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Assessing Competitive Strategies for the Joint Strike Fighter: Opportunities and Options

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PREFACE

Defense policymakers in the United States expect that the Joint Strike Fighter (JSF) will play a critical role in U.S. and allied military forces through the first half of this century. As U.S. Defense Secretary William Cohen stated in a June 2000 letter to Congress,

> The Joint Strike Fighter (JSF) program is critically important to the modernization of United States conventional forces and is the cornerstone of tactical aircraft modernization. It will replace 1,763 Air Force, 480 Navy, and 609 Marine Corps aircraft; 2,852 aircraft in total. The JSF's stealth, advanced avionics, and ability to carry a full array of modern precision munitions will make it much more capable than the legacy aircraft it replaces when operating under challenging circumstances against modern air defenses. It is also critical to the modernization of our ally forces for coalition welfare.[1]

The Department of Defense's current JSF acquisition strategy is a "winner-take-all" competition pitting Lockheed Martin against Boeing. This strategy has raised concerns as to whether competition should be retained after Lockheed Martin or Boeing is selected to begin engineering and manufacturing development.

In late July 2000 the Under Secretary of Defense for Acquisition, Technology & Logistics asked RAND to explore and identify opportunities and options to introduce competition during the production phase of the JSF. The principal criterion we used was the likelihood that such competition would reduce the overall cost of JSF production, which is expected to total ~$300 billion in then-year dollars. We made a more limited analysis of other plausible consequences, including savings in operation and support costs, reduction in cost growth, and improvement in product quality, to the extent possible within the study's four-month duration. We also explored how new competitive strategies might affect foreign participation in the JSF program. U.S. allies could account for sales of an additional 3,000 JSF aircraft.

This report should be of special interest to OSD, service, and defense agency managers and policymakers involved in weapons system acquisitions. It was prepared for the Under Secretary of Defense (AT&L), within the Acquisition and Technology Policy Center of RAND's National Defense Research Institute (NDRI). NDRI is a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies.

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[1] Cohen, W.S., Secretary of Defense, letter to the Honorable Jerry Lewis, Chairman, Subcommittee on Defense, Committee on Appropriations, U.S. House of Representatives, June 22, 2000.

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SUMMARY

The Department of Defense should stick with its winner-take-all strategy to develop and produce the Joint Strike Fighter (JSF). But as a hedge to ensure later versions of this next-generation aircraft—which is slated to become the workhorse fighter for the Air Force, Navy, and Marine Corps—have the most effective and innovative sensor, computer, and software technologies, the Pentagon should consider spending money to keep a second developer and producer of these vital electronics components in the market. Such an investment in a second producer of such missions systems, the electronics eyes and ears of the JSF, could be relatively modest. But it would provide future decisionmakers with the option to competitively develop a second mission system source when and if it were needed.

So concludes this study of competitive strategies for the Joint Strike Fighter. Performed over the summer and early fall of 2000, we examined both near and long-term competition options, some in more detail and more quantitatively than others, constrained only by the available time (about four months). Throughout the study we obtained critical information from the competing program contractors and the Joint Strike Fighter Program Office. While much of that information was considered competition sensitive by the firms, in this report we present only our own analysis and conclusions, thus permitting unrestricted distribution.

The bottom line is that putting one company or consortium of companies in charge of the overall production of the JSF makes the most economic sense. If two or more competitors developed and built this next-generation aircraft, the Pentagon likely would not see lower overall program costs. That's because producing such a sophisticated weapons system involves high front-end investments and non-recurring costs that probably would not be recovered through price reductions that might result from competitive forces. But at the same time, however, having several companies funded to develop and potentially produce later versions of the JSF mission system also may make sense. With technology changing at an increasing pace, the DoD could face the prospect of having its next-generation fighter employ less than the most innovative technologies. By funding continued technology development at the mission system level, defense policymakers might be able to lessen that risk.

THE PROBLEM

The JSF program is a joint effort among the U.S. Air Force, U.S. Navy, and U.S. Marine Corps with full partnership participation by the United Kingdom. The program objective is to

develop and deploy a family of highly common and affordable strike aircraft to meet the operational needs of the Air Force, Navy, Marine Corps, United Kingdom, and other U.S. allies.

The JSF will be one of the largest acquisition projects in history, worth some $300 billion (then-year dollars), and the only new major fighter aircraft program planned for the next 30 years. Over the next several decades these aircraft are slated to replace all F-16s, A-10s, AV-8Bs, and Harriers in U.S. and UK inventories and to augment the Navy's F/A-18E/Fs. By 2026 some 3,000 of the jet fighters are planned to be integrated into U.S. and UK forces. The DoD expects that additional sales to U.S. allies could approach 3,000 aircraft.

The DoD intends in Fall 2001 to grant one prime contractor the right to develop and produce all versions of the JSF. In 1996 the Boeing Company and the Lockheed Martin Corporation were named as the JSF's two finalist prime contractor competitors. Since then, each has been engaged in concept demonstration efforts, flown a test vehicle, and pursued other extensive preliminary development efforts—all in hopes of winning the JSF contract.

The DoD has been using this "winner-take-all" approach for decades; it has been the preferred method of developing, designing, and building sophisticated weapons systems. But as Boeing's and Lockheed Martin's efforts have unfolded, senior DOD officials and members of Congress have voiced concerns that awarding the JSF to one company could lead to a situation in which the United States might be paying more for weapons systems or purchasing less technologically sophisticated platforms than it would under more robust competition.

WHAT RAND WAS ASKED TO DO ABOUT THE PROBLEM

In late July 2000 the Under Secretary of Defense for Acquisition, Technology & Logistics asked RAND to explore and identify opportunities and options to introduce competition during the production phase of the JSF. The principal criteria we used was the likelihood that such competition would reduce the overall cost of JSF production. We made a more limited analysis of other plausible consequences, including savings in operation and support costs, reduction in cost growth, and improvement in product quality, to the extent possible within the study duration of approximately four months. We also explored how new competitive strategies might affect foreign participation in the JSF program.

HOW RAND STUDIED THE PROBLEM

The most direct approach to estimating the results of introducing competition would be to estimate the cost for a sole-source producer, then estimate the cost for a pair of competitive

producers, and compare the two. Unfortunately, we have no data or cost estimating relationships that would enable us to directly estimate production costs in a competitive environment. What we do have is some historical data showing the amount by which production cost changed when competition was introduced into ongoing sole-source production programs. Therefore, in this study we estimate the likelihood that the government would "break even" on the introduction of a competitive second source; that is, that the cost reductions would be great enough to pay for the incremental costs of introducing competition. If the likelihood is high, the government might reasonably elect to introduce competition in the expectation of achieving other potential benefits. Likewise, a low expectation of breaking even on production cost would discourage the government from introducing competition because the net dollar cost of production might increase enough to outweigh other possible benefits.

In our quantitative analysis, we developed a "breakeven" model, which was based on previous RAND studies that examined how competition might be introduced into the development and production phases of a variety of weapon systems. Our model was developed specifically for the JSF program and takes into consideration the multiple, unique aspects of the program. Using this model, we were able to gauge the likelihood that the DoD would recoup its costs if it invested in a second JSF producer. In particular, the model allowed us to look at whether lower JSF production costs engendered by the presence of a second producer would offset the DoD's investment in bringing that second source into the picture. This quantitative analysis relied on three main sources of information.

- Proprietary estimates from Boeing and Lockheed Martin of their designs' development and production costs, at a level of detail that enabled us to estimate costs under different production scenarios.
- JSF Program Office cost estimates for each variant, together with overall programmatic information on past and projected schedules of events, production quantities, and other information.
- RAND data on cost and cost estimating relationships for development, production and operation of U.S. fighter aircraft.

We augmented these sets of quantitative data with extensive discussions with both contractor teams and the project office staff regarding the feasibility and desirability of various competition strategies. This qualitative analysis allowed us to gauge whether the prospect of saving overall costs via a particular competition path was reasonable. We used the following to flesh out this part of our analysis:

- Studies and analyses on the results of prior efforts to introduce competition to a weapons production program. Because of the short time available for this study, our analysis of the historical record on the effects of competition on production cost was limited to a review of secondary sources—reports on previous studies of production cost changes due to competition. We examined the DoD's experience with introducing competition in 63 weapons system procurement programs between 1960 and 1990.

While useful, those reports rarely provided all of the information we needed to apply the historical results to the particular conditions presented by the JSF program. Nevertheless, we were able to assemble a body of historical data sufficient to support conclusions with useful confidence and precision.

OUR FINDINGS AND CONCLUSIONS

Whether and how much a second producer of a weapon system generates cost savings for the DoD depends on the type of hardware or system that the competitors are developing and manufacturing. The potential for cost savings also depends on the time frame—near-term or far-term—in which the competition is taking place.

Our examination of the DoD's past experience with introducing competition into weapons programs suggests that second producers of electronics have been more likely to generate savings in production costs than have second producers of missiles and ships. As Table S.1 shows, half of the DoD programs in our historical survey that involved two or more competitive producers of electronics were able to reduce overall costs by 30 percent, but only one in 10 competitive missile and ship production efforts were able to do so.

Table S.1

Fraction of Programs Examined that Achieved Savings

Savings Achieved (%)	Missiles and Ships	Electronics
>0	7/10	9/10
>10	5/10	8/10
>20	3/10	6/10
>30	1/10	5/10
>40	Nil	3/10

But such a 30 percent cost reduction is just the level of savings the DoD would need to achieve if it were to bring a second competitor into the JSF program. Our break-even analysis suggests that such a second competitor would need to offer the DoD this level of savings across a range of the JSF's elements—forward, center, and aft fuselage; landing gear; ejection seat; wing; edges; tail; and mission systems. Based on the DoD's past experience with missiles and ships, we found that such savings from competition would be difficult, if not impossible, for the JSF program to achieve in the near-term in any of these areas.

All these areas would be equally unpromising in the far-term, with the exception of mission systems. The mission system constitutes the eyes, ears and brain of the JSF and provides a powerful contribution to its overall combat effectiveness. Many of the enabling technologies are evolving much more rapidly than most flight vehicle technologies, and we can expect several major upgrades in missions systems during the life of the JSF. It therefore makes sense to begin preparing now for the first upgrade. We suggest that the DoD investigate the establishment of a "shadow" industry team that would begin developing system architectures and component technologies that would be tailored to the JSF but focused on technological advancement, cost reduction, and any new mission requirements that might emerge. That team would then be capable of competing to develop an integrated suite of mission equipment for a future upgraded JSF.

POLICY IMPLICATIONS THAT DERIVE FROM OUR FINDINGS

Our findings have two policy implications:

- *Policymakers should stick with the winner-take-all strategy for near-term development and production of the JSF.* Despite the potential advantages that might accrue, establishing a competitive production line for part or all of the JSF would require a front-end

investment, together with increases in recurring costs, that probably would not be recovered through price reductions that may result from competitive forces.

- *Policymakers should consider establishing a future competitor to develop and manufacture the next major upgrade of the mission system equipment.* This strategy would ensure that future managers have the option of a competitive second source, one that might not otherwise be available.

Our charter was to explore opportunities and options to inject competition into the JSF program, with the principal criteria being the likelihood that such competition would reduce the overall cost of JSF production. Our analysis shows that introducing competition for future upgrades to the mission system presents the most attractive option. Within the scope of our study we were unable to examine the idea in detail; we there recommend only that the notion be examined with an appropriate level of care and detail by the JSF management.

ACKNOWLEDGMENTS

This work could not have been undertaken without the special relationship that exists between the Office of the Secretary of Defense (OSD) and RAND under the National Defense Research Institute (NDRI). For that relationship we are grateful. Many individuals in OSD, British Ministry of Defence (MOD), JSF SPO, and RAND deserve credit for the work discussed in this report. Their names and contribution would fill several pages. If we were to single out a senior person at OSD, MOD; Joint Strike Fighter Program Office, and RAND who participated in and supported this work in extraordinary ways, we would mention Dr. Jacques S. Gansler, Under Secretary of Defense (Acquisition, Technology and Logistics); Sir Robert Walmsley, Chief of Defence Procurement and Chief Executive, Defence Procurement Agency; Col (sel) Darrell H. Holcomb, USAF, Director of Acquisition Strategy, Joint Strike Fighter Program; and Dr. Robert Roll, Program Director, Resource Management Program.

We also want to thank the leadership and staff of the Office of the Secretary of Defense, the British Ministry of Defence, the Joint Strike Fighter Program Office, and Boeing, Lockheed Martin, Northrop Grumman, Raytheon, BAE Systems, Rolls-Royce, Smith Industries, and Flight Refuelling. Each gave us the opportunity to discuss a broad range of issues with those directly involved; in addition, several of the firms arranged for us to visit their facilities. The firms and government offices provided all the data we requested in a timely manner.

This broad-based participation made possible the analysis described here.

We wish to thank RAND colleagues Frank Lacroix and Donald Stevens. Their thoughtful reviews occasioned many changes that improved the clarity of the report.

Lastly, the authors owe RAND colleague Joan Myers an incalculable debt for her thorough and patient administrative assistance at every stage in the project.

ACRONYMS

Symbol	Definition
AESA	Active electronically scanned array
AEP	Alternate engine program
BTP	Build-to-print
CAIV	Cost as an independent variable
CDP	Concept definition phase/concept development program
CGF	Cost growth factor
CNI	Communication-navigation and identification friend or foe
CTOL	Conventional takeoff and landing
CV	Carrier variant
DCASPRO	Defense Contract Administration Services Plant Representative Office
DIRS	Distributed infrared sensors system
DoD	Department of Defense
DT&E	Developmental test and evaluation
EMD	Engineering and manufacturing development
EW	Electronic warfare
FACO	Final assembly and check-out
FFF	Form-fit-function
FMS	Foreign military sales
FOT&E	Follow on test and evaluation
GD/C	General Dynamics Convair
HPCS	Historical production cost savings

I/O	Input/output
ICP	Integrated core processor
IPT	Integrated product teams
IR&D	Independent research and development
JAST	Joint Advanced Strike Technology Program
JSF	Joint Strike Fighter
LO	Low observable
LOA	Letters of offer and acceptance
LOL	Loss of learning
LRIP	Low rate initial production
MDAC	McDonnell Douglas Aircraft Company
MDAP	Major defense acquisition program
MIRFS	Multifunction integrated radio frequency systems
MOA	Memorandum of agreement
MOU	Memorandum of understanding
MWIR	Mid-wave infrared
ORD	Operational requirements document
O&S	Operating and support
OSD	Office of the Secretary of Defense
OT&E	Operational test and evaluation
PDRR	Program definition and risk reduction
PVI	Pilot vehicle interface
RCR	Required cost reduction
RCS	Radar cross section
RF	Radio frequency
SMS	Stores management system

STOVL	Short takeoff/vertical landing
TDP	Technical data package
UK	United Kingdom
URF	Unit recurring flyaway
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VMS	Vehicle management system

1. INTRODUCTION

This report summarizes RAND's analysis of options open to the Department of Defense to inject competition into various stages of production of the Joint Strike Fighter (JSF). Done quickly at the request of the Under Secretary of Defense for Acquisition, Technology and Logistics between July and October 2000, this study examines ways that defense policymakers may be able to lower the aircraft's costs or improve its quality by introducing competition during production.

Introducing competition into the JSF production process will not be easily or quickly done. The DoD intends in Fall 2001 to grant one prime contractor the right to develop and produce all versions of the new fighter, a production run that could exceed 3,000 aircraft, extend to 2026 or beyond, and be worth $300 billion or more in then-year dollars. The DoD in 1996 named the Boeing Company and the Lockheed Martin Corporation as the JSF's two finalist prime contractor competitors. Since then, each has been engaged in concept demonstration efforts, flown a test vehicle, and pursued other extensive preliminary development efforts—all in hopes of winning the JSF contract, the only new major fighter program planned for the next 30 years.

The DoD has been using this "winner-take-all" approach for decades; it has been the DoD's preferred method of developing, designing, and building sophisticated weapons systems. But as Boeing's and Lockheed Martin's efforts have unfolded, senior DOD officials and members of Congress have voiced concerns that awarding the JSF to one company could lead to a situation in which the United States might be paying more for weapons systems or purchasing less technologically sophisticated platforms than it would under more robust competition.

In late July 2000 RAND was asked to examine the possible consequences of introducing competition during the production phase of the JSF. The main focus of our study was to estimate the likelihood that such competition would reduce the overall cost of JSF production. We made a more limited analysis of other plausible consequences, including savings in operation and support costs, reduction in cost growth, and improvement in product quality, to the extent possible within the study duration of approximately four months. We also explored how new competitive strategies might affect foreign participation in the JSF program.

BACKGROUND

The JSF will be one of the largest acquisitions in history, worth some $300 billion (then year $) over the next quarter century. Some 3,000 aircraft—configured in a conventional takeoff

and landing (CTOL) version, a short takeoff and vertical landing (STOVL) version, or a carrier version (CV)—will be produced for the DoD. The JSF Program Office estimates that foreign customers could purchase an additional 3,000 aircraft.

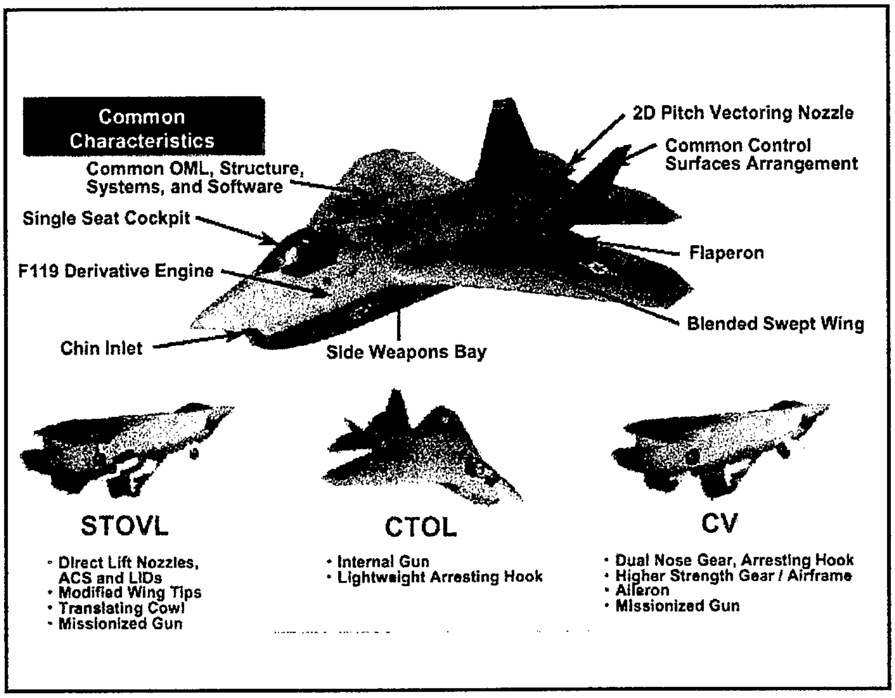
The JSF was conceived in the early 1990s as an aircraft that would meet the long-term needs of the three major U.S. services that operate fighter aircraft. It was designed to:

- Replace U.S. Air Force F-16s and A-10s;
- Augment carrier-based U.S. Navy F/A-18E/Fs; and
- Replace U.S. Marine Corps AV-8Bs and United Kingdom Harrier aircraft.

The JSF will be the first fighter program that attempts to satisfy the needs of three services with one platform. The DoD hopes that the version used by each service will have some 70 percent commonality with the other versions.

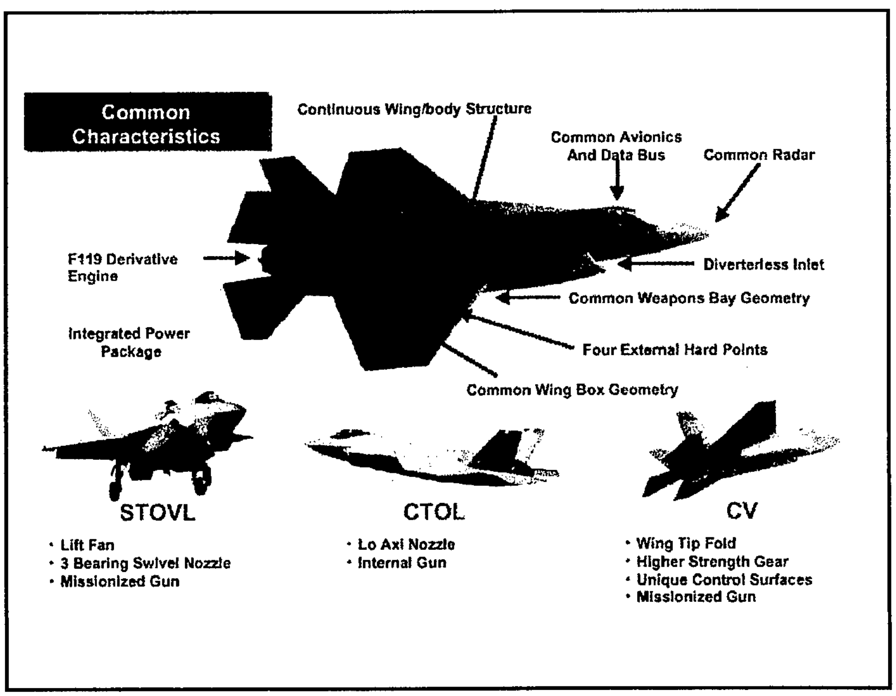
Some of the commonality features are illustrated in Figures 1.1 and 1.2, which show the Boeing and Lockheed Martin versions of the platform.[2] In theory, such commonality should make the JSF more affordable during production and throughout the service life of the aircraft. The DoD has established target prices for each version: $28 million for the CTOL, $30-$35 million for the STOVL, and $31-$38 million for the CV (in $1994).

[2] The designs shown represent the pre-proposal versions of the operational JSF and do not necessarily reflect the JSF configurations that will be proposed by the two firms.



SOURCE: Joint Strike Fighter Program Office

Figure 1.1—Boeing JSF Design



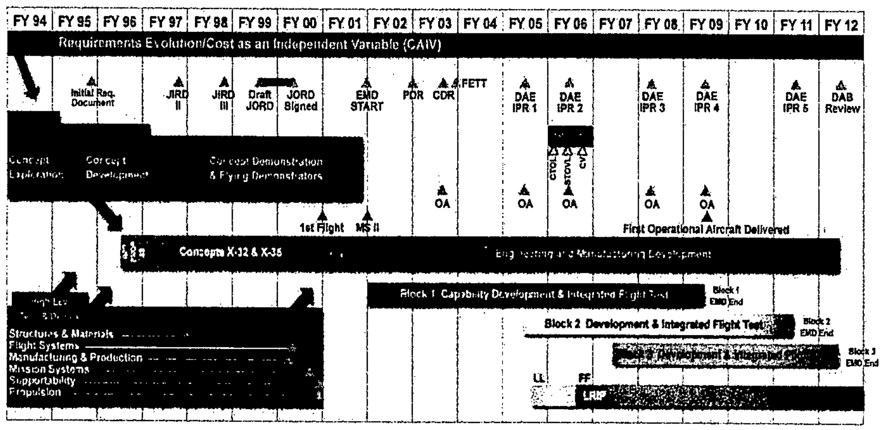
SOURCE: Joint Strike Fighter Program Office

Figure 1.2—Lockheed Martin JSF Design

The notion of a family of aircraft with a high degree of commonality that would satisfy such diverse operational needs poses an exceptional challenge to the designers. Only once before in recent history has an attempt been made to design one basic aircraft with versions that would perform land-based and carrier-based operations. That attempt failed and the carrier-based version of the F-111 was abandoned.[3] Those challenges have led to an unusually long and thorough period of requirements formulation, design analysis and technology demonstration in the JSF program.

As shown in the JSF program schedule in Figure 1.3, the contractors' concept demonstration and flying demonstrations began in FY1997 and will continue until late-FY2001. Both Boeing and Lockheed Martin flew test versions of their aircraft in late CY2000, and more test flights are slated through mid-2001.

Once the DoD chooses the JSF prime contractor, engineering and manufacturing development will begin. The Pentagon hopes to receive delivery of its first operational aircraft in early FY2009.



SOURCE: Joint Strike Fighter Program Office

Figure 1.3—Joint Strike Fighter Program Schedule

STUDY OBJECTIVES

RAND's involvement with this issue stems from a June 2000 letter that Secretary of Defense William Cohen wrote to Representative Jerry Lewis, Chairman of the Subcommittee on

[3] There have been carrier-based designs that were later modified/adapted to land-based operations with great success.

Defense in the House Appropriations Committee. "The Department has examined a number of options for continuing the JSF program once concept demonstration is completed," Secretary Cohen wrote. "These options all assume the selection of a single winning design. They range from winner-take-all to competition throughout production...We will continue to evaluate these options and to develop a comprehensive assessment that our successors can use as they make decisions on the future course of the JSF program. I have asked the RAND Corporation to review these options, including cost, and report back by December 1st."

SOURCES OF EVIDENCE WE DREW UPON TO MEET THE STUDY OBJECTIVES

Our analysis was based on four main sources of information. First, each of the prime contractor teams provided their own (proprietary) estimates of development and production costs for their individual designs, at a level of detail that enabled us to estimate costs under different production scenarios. Second, the JSF Program Office provided their own cost estimates, together with overall programmatic information on past and projected schedules of events, production quantities for each variant, etc. Third, we drew on our own internal stores of cost data and cost estimating relationships for development, production and operation of U.S. fighter aircraft. These sets of quantitative data were augmented by extensive discussions with both contractor teams and with the Program Office staff regarding the feasibility and desirability of various competition strategies. Our resulting quantitative analysis of the likelihood of achieving overall cost savings through any particular competition scenario was performed through use of a "breakeven" model that we developed, based on several previous studies of how competition might be introduced into development and production phases of other weapon systems.

The fourth important data source was the body of literature on the results of prior efforts to introduce competition to a weapons production program. Because of the short time available for this study (about three and a half months from go-ahead to final briefing), our analysis of the historical record on the effects of competition on production cost was limited to a review of secondary sources—reports on previous studies of production cost changes due to competition. While useful, those reports rarely provided all of the information we needed to apply the historical results to the particular conditions presented by the JSF program. Nevertheless, we were able to assemble a body of historical data sufficient to support conclusions of useful confidence and precision.

LIMITATIONS ON THE SCOPE OF THE STUDY

Competition is widely expected to stimulate a wide variety of actions by the producers in an attempt to make their product more attractive to the buyer. This study was almost entirely focused on two possible consequences of competition; changes in production costs and in operating and support costs. Several other possible consequences of production are briefly reviewed and those are factored into the overall conclusions, but only the costs of production and of operations and support are examined quantitatively.

Unfortunately, we have no historical or analytical methods for directly estimating reductions in production cost due to introduction of competition. Instead, we estimated the incremental costs of introducing competition and then, drawing on historical evidence, we attempted to estimate the likelihood that competition would drive down the costs enough to permit recovering those incremental costs and thus allow the government to at least breakeven on costs. The short time available for the study of previous competitive production programs limited us to a review of surveys done by others, and were unable to examine the original records of those past programs.

REPORT ORGANIZATION

The report is organized in ten chapters. Following the Introduction, Chapter 2 describes the overall JSF project, and Chapter 3 discusses some of the special features of competition in production of weapon systems and describes how the analysis of such competition can be viewed as a balance between benefits and liabilities. Chapter 4 summarizes the overall analysis process employed in this study, while Chapters 5 and 6 described the results of our analysis of the effects of introducing competition in production cost and on operations and support costs, respectively. Chapter 7 briefly reviews some of the likely benefits of competition other than costs. Chapter 8 summarizes the near-term options for introducing competition in the JSF program, and Chapter 9 explores some options for introducing competition in later phases of the program. Final conclusions and recommendations are presented in Chapter 10.

2. DESCRIPTION OF JOINT STRIKE FIGHTER PROGRAM

The Joint Strike Fighter (JSF) program is expected to be one of the largest and most costly acquisitions in history. Current plans call for the acquisition by the United States and United Kingdom armed services of more than 3,000 JSF aircraft, at a procurement cost of more than $300 billion (Then Year $). In an attempt to achieve commonality, variants of the JSF are planned eventually to replace a large percentage of the major fighter/attack aircraft in the current inventories of the U.S. Air Force, Navy, and Marines (in addition to British Royal Navy and Royal Air Force Harriers). This replacement is illustrated in Figure 2.1.

Following the completion of the current Concept Demonstration Phase (CDP), during which the two competing contractors (Boeing and Lockheed Martin) will fly concept demonstration aircraft (designated X-32 and X-35, respectively), DoD plans to select a single prime contractor in a "winner take all" strategy intended to maximize commonality among variants, and achieve maximum economies of scale. Therefore, the JSF program also has important industrial base implications. This aircraft could end up the only major fighter aircraft in production in the United States by 2020 or earlier, as shown in Figure 2.2. This compares to the early years of the current decade, which should witness the simultaneous production of at least three fighters (F/A-18E/F, F-22, and variants of the F-16 and/or F-15.) Thus, the U.S. Government could find itself relying on only one credible source to design, develop, and manufacture fighter aircraft by the 2020s.

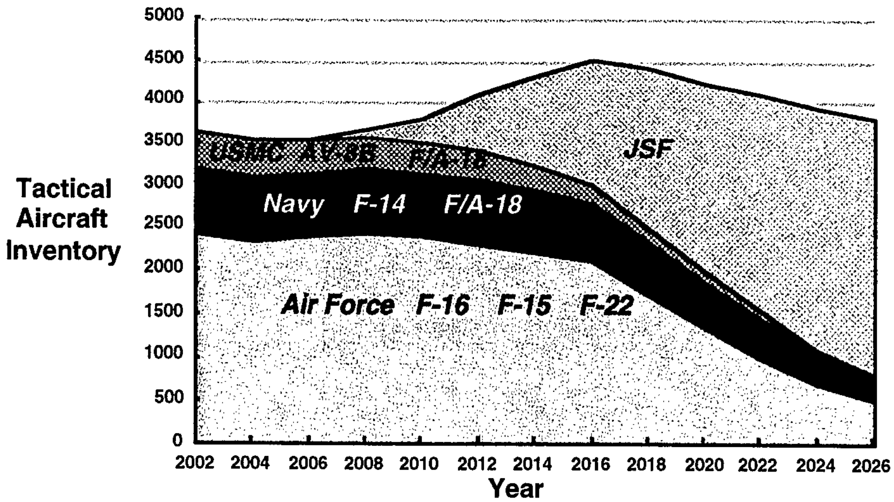


Figure 2.1—Projected Sequence of Production of Fighter/Attack Aircraft for U.S. Forces

The JSF is particularly important for the U.S. Marine Corps. Currently the Marine fixed-wing tactical aircraft inventory is made up of about 175 Boeing (McDonnell-Douglas)/British Aerospace AV-8B Harriers, a like number of Boeing (McDonnell-Douglas)/Northrop Grumman F/A-18C/Ds, and less than 100 F/A-18A/Bs. All of these aircraft are expected to be retired from the inventory between 2015 and 2021. Plans call for the delivery of the first STOVL JSF variant to the Marines in 2009. By 2011, deliveries are planned to stabilize at their peak level of 36 Marine STOVL variants a year, for an eventual total of 609 aircraft. Thus, by 2021, the STOVL JSF is expected to be the only tactical fighter aircraft in the Marine inventory. Furthermore, procurement of the STOVL variant is necessary to meet the Marine tactical fighter requirement by the mid 2020s.

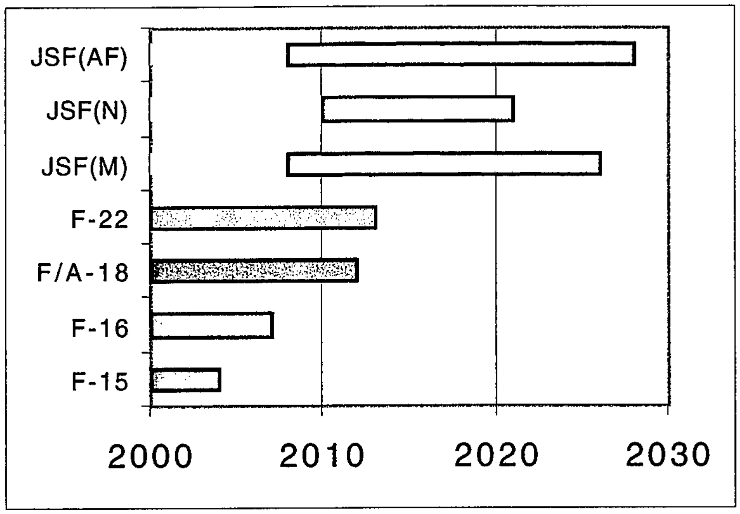


Figure 2.2—JSF Will Eventually Make Up Almost All of U.S. Tactical Air Inventory

JSF is also crucial for U.S. Air Force modernization requirements. Indeed, the Air Force will be the single largest customer for the program by far. Currently the USAF tactical fighter/attack inventory includes about 2500 aircraft, made up of nearly 1,400 Lockheed Martin (General Dynamics) F-16s, about 500 Boeing (McDonnell-Douglas) F-15s and 200 F-15Es, about 50 Lockheed Martin F-117 stealthy attack aircraft, and about 340 Fairchild Republic A/OA-10 attack aircraft. The Air Force plans to buy 339 Lockheed Martin F-22 air superiority fighters to replace the F-15 as the Air Force's premier air superiority fighter, and expects to begin receiving 1763 conventional takeoff and landing (CTOL) variants of the JSF beginning in 2007 to replace the F-16s and A-10s. By the mid 2020s, the JSF will make up about 70 percent of the Air Force tactical fighter inventory.

The JSF also plays a key role in the Navy's aviation modernization plans. Currently the Navy inventory is made up of fewer than 250 aging Northrop Grumman F-14 fleet air defense fighters, about 150 Boeing (McDonnell-Douglas) F/A-18A/B fighter/attack aircraft and about 350 F/A-18C/D fighter/attack aircraft. Beginning in 1998, the Navy began procuring the first of a planned 548 F/A-18E/Fs. These will replace the F-14s, which will be phased out of the inventory by 2008, and the F/A-18A/Bs, which will be gone by 2015. To maintain the full force structure size requirement as the F/A-18C/Ds begin retiring in large numbers by 2009, the Navy plans to start procurement of the Carrier Variant (CV) JSF beginning that same year. By the mid-2020s, the CV JSF is planned to make up approximately 60 percent of the Navy tactical fighter force structure. Full procurement of the planned 480 CV JSFs is necessary to meet the Navy tactical fighter force structure requirement.

Finally, STOVL versions of the JSF will replace 150 RAF GR.7 Harriers and Sea Harriers in Royal Navy service. The JSF and the Eurofighter are expected to become the principal tactical air assets of the U.K.

As far as the U.S. services are concerned, JSF is unprecedented in the history of tactical combat aviation in its scale and overall importance for the future of the force structure. Overall, by the mid-2020s, JSF variants are planned to make up more than 70 percent of the total U.S. tactical fighter force. The only other tactical fighters that will remain in the inventory at this time in significant numbers will be the F-22 and the F/A-18E/F.

ORIGINAL ACQUISITION PLAN AND PROGRAM PRIORITIES

From the early phases of the JSF program, the intent of acquisition planners was to structure the program differently from past programs in order to reduce overall costs of ownership. DoD designated JSF a flagship program for acquisition reform. Changes to traditional acquisition approaches concentrated on six broad areas: service commonality, the acquisition cycle, the requirements determination process, technical risk reduction, extended design and subsystem competition, and foreign participation.

Early in the program it was decided that to reduce costs through increasing economies of scale, and to promote interoperability, variants of the same basic aircraft design would be used to satisfy the tactical fighter modernization requirements of three services: Navy, Air Force, and Marines. The competing contractors were encouraged to maximize commonality among their three variants so that they could use the maximum possible number of identical or similar airframe parts, as well as avionics, engine, and other subsystems. The intent was that all three variants could be assembled using a large number of common or similar parts and components.

Planners established a Program Office much earlier than is usual with numerous Integrated Product Teams (IPTs) representing most of the major stakeholders from the acquisition, user, and support communities. In addition, the traditional Concept Exploration and Program Definition and Risk Reduction (PDRR) phases were combined into a single Concept Demonstration Program (CDP).[4] The longer CDP permitted a much lengthier period to conduct

[4] To be completely accurate, the Joint Advanced Strike Technology (JAST) Program, which preceded the JSF program, did have a Concept Exploration phase which lasted through most of CY1994. JAST however was not formally viewed as an acquisition program, but rather as a technology exploration program. The main achievement of the JAST Concept Exploration phase was the conclusion that variants of a single basic design could meet the tactical fighter modernization requirements of all three U.S. services. In addition, the first part of the CDP

more extensive cost/benefit trade-off analyses, technology assessment, and requirements definition.

The requirements determination process was far more drawn out and iterative than in a traditional DoD acquisition program. From FY1995 through FY1999, three joint initial requirements documents (JIRDs) were developed through an iterative process which included all stake holders. Vigorous application of the acquisition reform concept of Cost As an Independent Variable (CAIV) was promoted during this period. The CAIV concept raises cost goals to the same level as performance and other system requirements. Indeed, early in the program specific Unit Recurring Flyaway [URF] cost threshold targets were established that became key requirements: $28 million for the CTOL variant, $31-38 for the CV variant, and $30-35 million for the STOVL variant (costs in FY1994 dollars). This resulted in the user communities having to make trade-off decisions on the costs and benefits of various performance requirements in order to keep the aircraft design within the target URF cost goal. The process of developing initial requirements documents led in FY1999 to the writing a draft Operational Requirement Document (ORD). This in turn went through one more iteration, resulting in a final ORD in mid FY2000.

Technical risk reduction is discussed separately in a section below. Suffice it to say here that throughout the CDP many technology risk reduction and demonstration programs were funded by the Program Office in higher risk technology areas.

Throughout the CDP, competition at the prime and subsystem level was emphasized. During the first year of the CDP[5], three prime contractor teams competed: Boeing, Lockheed Martin, and McDonnell Douglas/Northrop Grumman/British Aerospace.[6] In November 1996, DoD selected Boeing and Lockheed Martin to complete the CDP. These two prime contractors would continue to compete until the selection of a single winner-take-all for the Engineering and Manufacturing Development (EMD) phase, now expected to begin in the Fall of 2001. In late 1995 the Alternate Engine Program (AEP) was launched with a $7 million contract awarded to General Electric teamed with Allison (Rolls Royce). Originally, the Pratt & Whitney F119 engine had been selected for use by all of the prime contractors for their JSF designs. The AEP provided

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beginning in November 1994 was originally referred to as the Concept Definition and Design Research Phase.

[5] Also known as the Concept Definition and Design Research Phase, which lasted from November 1994 to November 1995.

money for the ultimate full-scale development of the GE F120, so that it would be available as a competitive alternative to the P&W F119 after the initial JSF production phases are completed in the early 2010s. In a like manner, competitive technology programs were funded for many other major subsystems such as the fire control radar, although these had not originally been intended to continue beyond the beginning of EMD.

Each contractor is building and flight testing two demonstrators. Boeing's X-32A and Lockheed's X-35A both first flew in the second half of 2000. These aircraft are intended to demonstrate basic design characteristics in three areas: short take-off and vertical landing, low speed carrier approach and flying capabilities, and commonality and modularity for cost effective variants for the three services.

INTERNATIONAL PARTICIPANTS

The JSF program is unique in that it has included significant foreign government and industry participation from its earliest phases. The reasons for seeking early and significant foreign participation are as follows: to enhance equipment interoperability with allies, promote foreign acquisition of the aircraft, to share the financial burdens of development and production, to share U.S. know-how with important foreign allies, and to gain access to unique technologies and capabilities available from key allies.

There are four official levels of foreign government participation during the CDP:

- Full Collaborative Partner;
- Associate Partner;
- Informed Partner, and
- Foreign Military Sales (FMS) Major Participant.

Full Collaborative Partner. The United Kingdom is the foreign participant with the most significant involvement in the program. It is the only Full Collaborative Partner on the program for the CDP portion. The U.S. and UK governments signed a Memorandum of Understanding (MoU) on Royal Navy program participation in 1995. The MoU was modified in 1999 to include the Royal Air Force. The UK is contributing $200 million to the CDP.

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[6] Subsequent to start of CDP, Northrop Grumman and British Aerospace (British Aerospace became BAE Systems on 30 November 1999) joined the Lockheed Martin team and Boeing merged with McDonnell Douglas.

The UK actively participates in the process of developing JSF requirements documents. The stated objective of the U.S.-UK MoU is to promote harmonization between UK system requirements and the requirements of the U.S. services. UK personnel are included on several IPTs. By the later stages of the CDP, the UK held eight country representative positions at the Program Office, in addition to a National Deputy at the Director level.

Associate Partner. Three countries have Associate Partner status during CDP: Denmark, the Netherlands, and Norway. These three countries jointly negotiated agreements that were signed on different dates in 1997. Each country contributed $10 million, which was matched by a U.S. contribution of $30 million, for a total of $60 million. The primary objective of their participation in the CDP is to influence requirements development for the CTOL JSF variant. In line with the terms of the MoUs and Memorandum of Agreement (MoA), associate partners may influence requirements as long as they and the United States perceive the results to be mutually beneficial. Each associate partner is represented by one National Deputy and one technical representative during the CDP.

Informed Partners. Canada and Italy participate as Informed Partners. The United States signed an MoU with Canada in January 1998, and an MoA with Italy in December of the same year. Informed Partners do not have the authority to influence requirements. Canada's participation is aimed at cooperating with design refinements of the CTOL version, and other associated activities. Italy is involved in a variety of tasks related to the Italian Navy's interest in the STOVL variant and the Italian Air Force's interest in the CTOL variant. Canada and Italy are each contributing $10 million toward this joint activity. The United States contributes $50 million to the joint U.S.-Canadian activities.

Foreign Military Sales Major Participant. There are three FMS major participants in the CDP: Turkey, Singapore, and Israel. All three signed Letters of Offer and Acceptance (LOAs) during 1999. All FMS major participants are involved in the generic JSF project, which provides extensive unclassified and non-propriety information about JSF requirements and designs. Each of the three FMS major participants takes part in a variety of different aspects of the CDP. Turkey committed to a contribution of $6.2 million; Singapore and Israel are contributing $3.6 million and $0.75 million respectively. There is no U.S. financial contribution to these joint FMS Major Participant efforts. A summary of CDP foreign participation is shown in Table 2.1:

Table 2.1

International Participation in JSF CDP

Country	Status	Agreement	Foreign Contributions	U.S. Contributions	Date Joined
United Kingdom	Full Partner	MOU	$200 M	-	Dec 95
Netherlands	Associate Partner	MOA	$10 M	$10 M	Apr 97
Norway	Associate Partner	MOU	$10 M	$10 M	Apr 97
Denmark	Associate Partner	MOU	$10 M	$10 M	Sept 97
Canada	Informed Partner	MOU	$10 M	$50 M	Jan 98
Italy	Informed Partner	MOA	$10 M	-	Dec 98
Singapore	Major Participant	LOA	$3.6 M	-	Mar 99
Turkey	Major Participant	LOA	$6.2 M	-	Jun 99
Israel	Major Participant	LOA	$0.75 M	-	Sep 99

As of late 2000, negotiations were under way with many of these countries as well as others regarding the possibility of developing agreements for participation in EMD. According to press accounts, four levels of EMD participation will be available for foreign partners: Levels 1, 2, and 3, and FMS. Level 1 will require approximately a 10 percent contribution to EMD costs. Level 2 will require about 5 percent, and Level 3 on the order of 1 to 2 percent.

The United Kingdom will be the only Level 1 EMD participant. This status provides full representation at the JSF Program Office. The United Kingdom will participate in the evaluation of the CDP flight demonstrators, as well as in the selection of the winning design.

Italy, the Netherlands, and Turkey may be Level 2 participants in EMD. If they join, they will be able to exercise some degree of influence over the EMD program. Level 2 participants will have two to five representatives at the JSF Program Office.

Canada, Norway, and Denmark have been mentioned as possible Level 3 participants in EMD.

Many other countries have reportedly been invited to take part in EMD as Level 2, Level 3, or as FMS participants.

Industries from virtually all the participants in the CDP are represented on the two prime contractor teams developing the demonstration vehicles. This is discussed in Chapter 7.

CONTRACTOR RESPONSIBILITIES

The two U.S. lead prime contractors and their major partners have an unprecedented degree of design and configuration control and responsibility. The ORD is stated primarily in terms of broad performance parameters and URF costs. The contractors have been granted considerable freedom in developing designs, selecting subcontractors, and choosing technologies to meet the performance and cost requirements. For example, each prime contractor has selected different technological approaches to the STOVL lift system, as well as in many other areas such as the electro-optical/infrared systems, the fire control radar, mission computer architecture, and so forth. Thus, the contractors are responsible for achieving the required capabilities (performance, reliability, supportability, etc.) within the cost goals established by the government, but the way they do this is left up to them.

RISK MANAGEMENT

Early on the JSF Program Office identified areas of relatively high technical and programmatic risk, and initiated programs to reduce risk. The main approach selected to manage risk was to fund numerous competitive hardware demonstration programs. One good example is the multifunction integrated radio frequency systems (MIRFS) program. The purpose of the MIRFS program was to encourage companies to develop much lower cost, lighter active electronically scanned arrays (AESAs) for fire control radars. In an unprecedented risk reduction effort, the JSF Program Office funded a five-year, $110 million program beginning in February 1996. Contracts were let to the two leading U.S. fire control radar contractors, Hughes Aircraft, which later merged into Raytheon, and Northrop Grumman Electronic Sensors and Systems Sector (ESSS). During CDP, Raytheon was the radar source to Boeing and Northrop Grumman/ESSS was the supplier to Lockheed Martin. Both companies undertook major efforts to develop new technology and manufacturing processes to dramatically reduce cost and weight of AESAs. The programs included flight demonstrations of prototype arrays incorporating the new technologies.

The JSF Program Office funded many other similar technology risk reduction programs. These included the structures and materials programs, the avionics virtual systems engineering prototyping program, the joint visual system operational evaluation program, and many others.

These technology management and risk reduction programs differed in several ways from past programs. First, they were more directly linked to specific preferred weapon system concepts being developed by the prime contractors. Second, they often included two competing

contractors undertaking the same type of R&D. Third, they were often larger, longer and more generously funded than similar types of programs in the past. Finally, they often required development and flight testing of a full-scale flight demonstration of the actual hardware, rather than laboratory demonstrations.

Of course the most dramatic example of this approach was the requirement of the JSF two competing prime contractors to develop and flight test demonstration aircraft as discussed above.

CURRENT COST AND SCHEDULE

The selection of the winner of the JSF program and the beginning of EMD have been delayed about six months, to Fall 2001. The delay has been caused by a variety of reasons, including DoD's desire to examine alternative competition strategies for JSF EMD and production, and to further examine the industrial base implications of a winner-take-all strategy that may lead to the exit of the losing contractor from the fighter aircraft business. Also, there is a widespread recognition that a new administration, whether Democrat or Republican, will likely want to conduct a major review of U.S. tactical fighter modernization programs before launching JSF full-scale development.

JSF EMD is still budgeted for about $20 billion (FY94$) and is planned to last a little over 10 years. Fourteen preproduction flight test aircraft will be built and flown during EMD. LRIP 1, scheduled for 2008, may now slip due to a variety of factors. Initial operational capability for the first JSF unit is planned for late 2010 in the U.S. Marine Corps with the STOVL version. The U.S. Air Force will receive its first operational CTOL version in 2011 while the U.S. Navy (CV version) and United Kingdom (STOVL version) will get their first operational versions in 2012. LRIP V is expected to accomplish this goal in 2012 with a production output of 115 aircraft.

3. COMPETITION DURING PRODUCTION: BENEFIT OR LIABILITY

The JSF program has been intensely competitive since 1996, with two firms, Boeing and Lockheed Martin, currently flight testing demonstrator aircraft. However, the present plan calls for one contender to be eliminated in the Fall 2001, with the winning firm performing all further development and manufacturing of the JSF.

This winner-take-all prospect raises the following question: should some kind of competitive posture be retained further into the program? If so, how should it be structured? In this chapter we examine (1) some of the special conditions that exist in defense procurement, and the consequent balance of costs and benefits created through introduction of competition; and (2) the range of possible advantages and disadvantages the government might experience from sustaining competition through production.

THE SPECIAL NATURE OF COMPETITION IN DEFENSE PROCUREMENT

The special nature of the environment for competition in defense procurement can be illustrated by comparing it with the conditions usually assumed in the economist's model of the perfectly competitive market. This comparison will help in understanding why there are inherent difficulties in introducing effective price competition into defense acquisitions. It will also provide a key to understanding the variety of competition-enhancing arrangements that have been developed. Table 3.1 compares the characteristics assumed for the perfect-market model with the corresponding characteristics of a typical system acquisition in which no special arrangements have been made to introduce competition in an attempt to achieve price savings or other objectives.

The high priority the defense buyer usually gives to product quality is sometimes regarded as a defect in the acquisition process. The conventional wisdom is that when programs experience difficulties, expenditure is the first constraint to be relaxed and schedule the second, but that performance goals are adhered to quite rigorously; the result being that the unit price of the product increases.

The data support this description of the way quality, schedule, and price are traded off,[7] but it is by no means clear that this should be accepted as adverse criticism. The services' emphasis on high system quality is consistent with the long-established national policy that relies on quality rather than quantity for defense, and hence calls for the development and production of systems superior to those fielded by possible opponents. If this is accepted, the question is not so much whether quality should be given priority, but rather, what kind of quality and how much quality is enough? This latter question, however, is peripheral to what concerns us here. It is sufficient to recognize that major system acquisitions generally aim at a quality of product that requires innovations in design and the application of advanced technologies, with all the technical uncertainty this entails.

Another conventional view about the defense-system acquisition process is that it consists of a small number of quite separate and distinct steps or phases, defined by major "milestone" decisions made in the Office of the Secretary of Defense (OSD). From a certain policy standpoint, this phased viewpoint is reasonable representation. The milestone phases are convenient for some management and descriptive purposes; however, they do not reveal the truly complex nature of the relationship between buyer and contractor.

Table 3.1

"Perfect Market" Versus Typical Market Characteristics in Major Defense System Production

Perfect Market Characteristics	*Major Defense System Market Characteristics*
Many buyers and producers, none being dominant; each buyer has a choice of many producers. To a close approximation, price (a firm fixed price) is determined by the "hidden hand" of the market.	*Only one buyer. Usually only one producer—the prime contractor who developed the system. Production prices (seldom truly firm-fixed prices) are determined by a series of negotiations in a sole-source environment*
Product is an existing, standardized item, the same for each producer—it is "homogeneous," and its characteristics are stable over time.	*Product is a newly developed item, usually without close substitutes and with a design that is periodically upgraded during much of the production phase and often even afterwards*
Competition focuses on price alone	*Prospective producers compete early in the development phase through "design rivalry." Buyer is concerned with product quality (especially performance), delivery schedule, and other nonprice factors. Price is not the dominant consideration in selecting the producer; quality of the product is normally given priority.*

[7] See, e.g., Edmund Dews and Giles Smith, et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, Santa Monica, Calif.: RAND, R-2516-DR&E, 1979, pp. 48 et seq.

Table 3.1 (Continued)

"Perfect Market" Versus Typical Market Characteristics
in Major Defense System Production

Perfect Market Characteristics	*Major Defense System Market Characteristics*
No producer has an advantage in production technology or economies of scale	*Production technology is dynamic and may differ among prime contractors and their subcontractors. Economies of scale, including "learning-curve" and production rate effects, significantly influence producer costs. A superior developer is not necessarily a more efficient producer.*
Market is easy for new producers to enter	*New prime contractors seldom enter the defense sector; entrance is inhibited by the high capital investment required, the proprietary rights of others, and the administrative and contractual burdens of a highly regulated industry.*
Buying the product is a simple, quickly completed, one-step transaction between the buyer and the producer, independent of other purchases from the same or other producers	*Acquiring a major system is a multiyear, multistep, complex process, involving scores of successive, usually interdependent contract negotiations between buyer and producer.*
Market is characterized by perfect intelligence and absence of uncertainty. Information about product price, standards of quality, number of items purchased, and delivery schedule is freely available to all concerned	*Uncertainty is a dominant and largely unavoidable feature. Among the market uncertainties are the* • *threat the system will face* • *most suitable system capabilities* • *best design approach* • *feasibility of development* • *time and other resources required to complete development and make the transition to production* • *deficiencies that may be revealed by operational testing*

Phases in Buyer-Contractor Relationship

All programs must accomplish certain activities. The framework in which these activities occur is called the Acquisition Process and is graphically depicted in Figure 3.1.

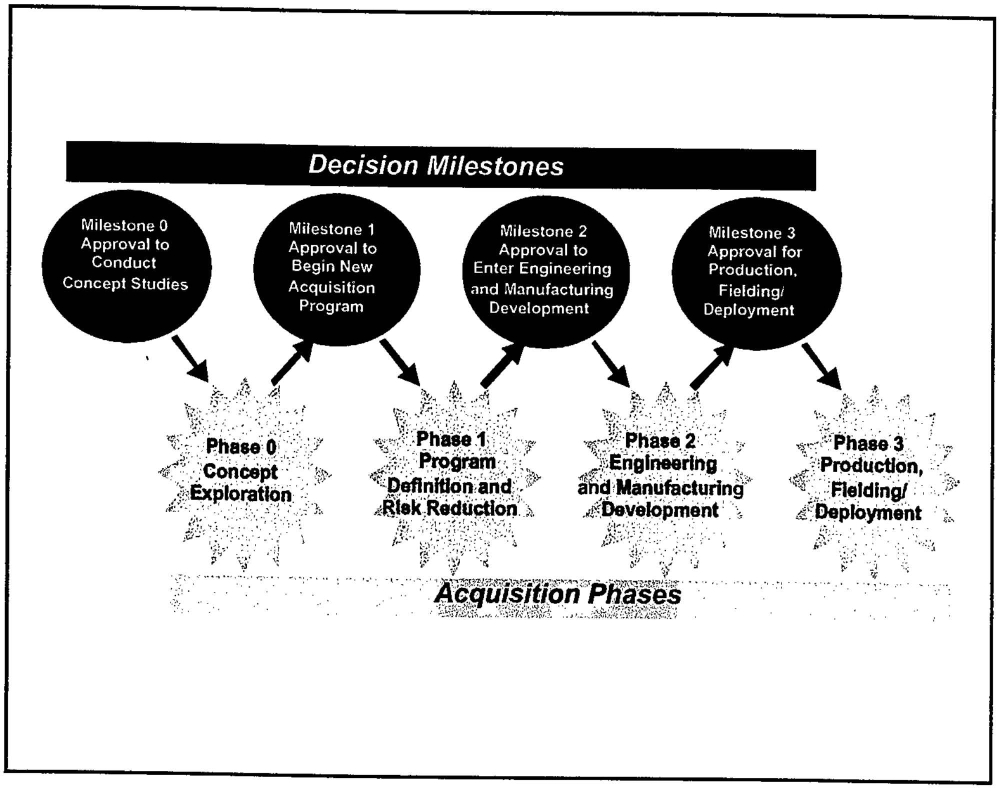

Figure 3.1—Acquisition Process and Phases[8]

The buyer-contractor relationship involves four phases—Concept Exploration, Program Definition & Risk Reduction, Engineering and Manufacturing Development (EMD), and Production. Each phase is triggered by a milestone decision.

Concept Exploration. Milestone 0 approval begins the process and authorizes entry into Concept Exploration phase. The Milestone Decision Authority specifies the minimum set of alternatives to be examined, the lead organization, and exit criteria. In the Concept Exploration phase, a statement of need has been agreed upon. The focus of this phase is to define and evaluate the feasibility of alternative concepts and to provide a basis for assessing the relative merits of these concepts at the next milestone decision.

Program Definition and Risk Reduction. After a go-ahead decision has been made at Milestone I, the Program Definition and Risk Reduction phase (Phase I) begins.[9] At this point the

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[8] Source: Joseph H. Schmall, *Introduction to Defense Acquisition Management,* June 1996, Defense Systems Management College Press, Fort Belvoir, VA.

[9] Before Milestone I, some prospective prime contractors may have been informally consulted, performed special studies under contract, or submitted unsolicited proposals.

acquisition strategy and concept baseline are approved. Exit criteria that must be accomplished during Phase I are established.

Phase I is characterized by measures designed to reduce the risk of incorporating new and emerging technologies. Contractors put forward designs and their feasibility is assessed; prototypes may be built and compared ("fly before buy"); preliminary estimates are made of system performance, schedule, and price; and the tradeoffs among them are considered. However, the emphasis is on assuring the feasibility of system design and the capabilities it promises, and on reducing any inherent risks to levels deemed appropriate for moving to the next phase.

Engineering and Manufacturing Development. The next step—Engineering and Manufacturing Development (EMD)—begins with a go-ahead decision at Milestone II. Proposals for EMD are requested from several contractors—almost always from the relatively small number of primes that participated in Phase I. These proposals describe rival designs and their estimated capabilities in much more specific detail (especially if prototypes have been built and tested) and estimate schedule and price more realistically. In most cases, because of the high cost of EMD, only a single prime is chosen in the "source-selection" process. The task of the EMD contractor(s) is to bring development to a point where the transition to production can begin, and EMD contracts usually call for some initial output of full production-configured units at low production rates. Manufacturing and production processes are validated. There is a heavy emphasis on testing—developmental test and evaluation (DT&E) to ensure specifications are met, and operational test and evaluation (OT&E) to ensure the system is operationally effective and operationally suitable. OT&E is usually conducted using the full production-configured units noted above.

In the selection of an EMD contractor, price receives substantially more attention than in earlier phases; for example, design-to-production-price goals may have been established in the request for proposals. However, it is recognized that the contractor's "cost" estimates for EMD and production are still subject to much revision, typically upward. The choice of the prime contractor(s) for EMD is normally weighted in favor of expected system quality, with price as an important but still secondary consideration.

Production. The fourth step in this conventional description of the buyer-contractor relationship begins with a favorable Milestone III decision—the decision to proceed to full-rate production of the system. A production contract is then negotiated, and, if there has been only a single prime contractor in the EMD phase, the negotiation is conducted in a sole-source environment. This phase often overlaps Phase II, especially in cases where a low rate of initial

production (LRIP) is a part of the program acquisition strategy. The system is produced and delivered (along with support infrastructure) to the field of operational use. Follow-on Operational Test and Evaluation (FOT&E) may be conducted, to assess performance and quality, compatibility, and interoperability. System status is monitored to ensure the system continues to meet the user's needs. During deployment and throughout operational support, the potential for modifications to the fielded system continues.

At the end of a system's useful life it must be demilitarized and disposed of. During this portion of the system life cycle, the project manager must ensure the materiel requiring demilitarization is controlled. The project manager must also ensure that disposal minimizes DoD's liability due to environmental, safety, security, and health issues.

NUMEROUS CONTRACT NEGOTIATIONS COLOR BUYER-CONTRACTOR RELATIONSHIP

This four-step description of buyer-producer relationships is much more complicated than the one-step transaction postulated in the perfect-market model. Moreover, reality is even more complex. The complexity of the buyer-producer relationship is reflected in the large number of sequential contract negotiations that take place between the buyer and the prime during the course of the acquisition process. This large number of negotiations is the result of several interrelated factors (see Table 3.1), including the following:

Many sources of continuing uncertainty during acquisition:

- Very long program duration
- A product changing over time, with development continuing through and usually beyond the production phase
- A widespread institutional preference for short-term, sequential decisions

For a single major acquisition, the contractual relationship between the government and the prime may continue over 20 years or more—beginning with (or even before) Phase I and ending with the last post-production upgrade or prime-contractor-handled spare-parts purchase.

This decades-long buyer-contractor relationship in major system acquisitions is one reason for the numerous contract negotiations that occur. Another reason is the widespread institutional preference on the buyer's side for short-term, sequential decision-making. Congress has preferred to exercise control through annual appropriations, even when multiyear contracts

are approved; and most major-system contracts (or contract amendments) are negotiated for a single year's buy.

Because of uncertainties about the threat and, especially, uncertainties about future-year funding levels, allocation decisions, and the timing of new starts, the services have generally preferred to retain programming flexibility by avoiding long-term contractual commitments.[10]

Contract administrators and auditors prefer short commitments, so that they can close out contract files in a few years and avoid long and complex audit trails. Compared with longer-duration contracts, short-term, quickly completed contracts may also have financial benefits for the government. For example, by shortening the contract period, the contractor receives his profits sooner and resulting taxes become payable sooner.

Program managers, during EMD and the early years of production, want the contractual flexibility to make desirable design tradeoffs, fund major design changes, and approve at least some of the many apparently well-justified engineering change orders that are almost inevitably proposed at this time. These actions require frequent contract renegotiations or the negotiation of contract amendments. Other, often separate, contract negotiations can involve such things as long-lead-time procurements, additional test items and test support, initial and other spares, data rights, special studies, foreign assistance, new subsystems, and retrofits.

The result is that the contractual relationship between the buyer and the seller is neither the one-step transaction of the perfectly competitive market nor the four-phase transaction implied by the OSD milestone decisions.

THE BENEFITS AND DRAWBACKS OF COMPETITION

In a government procurement, competition can have both benefits and drawbacks, which are depicted in Table 3.2. The measurement of past effects has produced a variety of answers, some of them conflicting. We need to carefully examine each situation, assess the likely benefits and drawbacks, and reach a judgement on the expected balance between them.

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[10] Some members of the armed services, however, have argued for greater use of multiyear contracts as a means of "locking in" stable funding for favored acquisitions, even at the cost of decreasing the stability of other acquisitions.

Table 3.2

Benefits and Drawbacks of Competition in Defense Acquisitions

Benefits	Drawbacks
Reduced prices	Additional front-end time and money needed
Staffed with best employees	Extra management complexity and effort required
Enhanced product quality through technology insertion and design refinement	Few, if any, near-term benefits
Strengthened industrial base	

Benefits of Competition

Most observers argue that competition produces many significant benefits.[11] Competition improves product quality and lowers unit costs, they say, compared with a noncompetitive environment. Competition forces manufacturers to quickly learn about new technologies and production techniques, fostering greater technological progress and industrial productivity. Finally, competition allows for a more equitable process under which acquisition contracts are awarded.

We do not question the value of competition as a means of inducing a firm to reduce prices. When competition or the threat of competition is perceived as real, a firm can act in a number of ways to cut costs and price. Managers often assign their best people to a competitive program, allocate corporate capital for equipment, and fund value-engineering studies (rather than expecting the customer to fund them). A company can transfer production from an area of high labor costs, such as California or Massachusetts, to locales where labor costs are lower.

Also, management can take measures to substitute capital for labor, accelerate cost-reduction schemes, and seek out alternative vendors. A firm may be able to operate at an economical rate by producing enough parts in a few months to satisfy the contractual requirement for an entire year, and then assign the workers to other tasks for the remainder of the year. In addition, a company is often able to reduce the number of engineering and

[11] K.A. Archibald, et al., *Factors Affecting the Use of Competition in Weapon System Acquisition*, Santa Monica, Calif.: RAND: R-2706-DR&E, 1981.

manufacturing support personnel assigned to a program. Noncompetitive programs tend to be heavy in such personnel, often because the customer wants to retain the services they provide.

It is difficult to assess the effect of competition in the abstract. A contractor who needs business or is determined to increase market share acts differently from one who does not.[12] Savings are contingent on speculation about what might have happened if a second contractor had not been brought into a program and assumptions about estimates of program cost without competition. If that estimate is too high, savings from competition or other causes would be easy to achieve. If it were too low, savings would be unlikely.

National security considerations also may dictate having two producers for a system or subsystem. Improved quality assurance often is cited as a reason for second-sourcing. In some instances, the underlying reason has been a profound dissatisfaction with the initial contractor, which may be a good developer but an inefficient producer. The nature of defense procurement is such that once a contractor is chosen to develop a major new system, the responsible military service is locked into a relationship with that contractor that could last 20 years or more. Bringing a second company into a program is an effective way to encourage greater cooperation from the initial firm.

Drawbacks of Competition

Barriers to competition also exist. Observers note that competition requires additional time and money. Competition entails extra management complexity and effort. Because most of the benefits of competition are long-term, not near-term, program managers have few incentives to implement competitive steps. Further, competition has uncertain and mixed results. In a risk averse environment, this uncertainty reduces the program manager's incentive to use competition.

In discussing each drawback below, we attempt to distinguish among different problems that arise during discrete phases of the acquisition cycle.

Additional Time and Money

At almost every phase in the acquisition cycle and for almost every kind of competition, adding a second competitor initially costs more than the cost of a sole-source. During the Concept Exploration phase, such funds are relatively small in absolute terms, although large in

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[12] Willis R. Greer, Jr., and Shu S. Liao discuss the "hungriness" factor in *Cost Analysis for Dual Source Weapon Procurement*, Naval Postgraduate School, NDS54-83-011, October 1993. Their

comparison with the overall funds available in that budget category. But competition during the concept exploration phase is a well-established tradition, so funding for multiple sources is relatively easy for a manager to obtain.

When the program moves to EMD, the magnitude of the funding required for a second, competitive source becomes large in both relative and absolute terms. Furthermore, while general statements supporting competition occur at every level in the defense establishment, this verbal support does not mean that everyone concerned with a particular program will be willing to fund competition. When the funding required to support a second, competitive source reaches the level of tens or hundreds of millions of dollars, authorization will have to come from higher up the chain-of-command. This means that many people will have to be "sold" on the competitive action. At every level in the organization, there will be some who are sympathetic to the request for funds, and others will see themselves as competing for the same funds. Some groups will tend to underestimate the difficulty of developing a particular system or have an interest in fielding it very quickly, and will thus resist competition during full-scale development on the grounds that it is a waste of time and money. The situation is even more complex in multi-service programs where each of the services must agree to put up the extra money.

When substantial amounts of money are involved, the DoD and the Congress must be sold on the competition as well. When there is no great pressure for competition and when other acquisition initiatives are being emphasized, DoD and Congress can be difficult to convince. Congress tends to dislike programs with heavy front-end cost, and other, less obvious, political problems sometimes intrude.[13] Also, funding requests are reviewed by four different Congressional committees that do not automatically coordinate their decisions; so, each must be persuaded separately. It is not unusual for one committee to support a competition and another to delete the funds for it.

Further, once funding for a competition is approved, there is no guarantee that it will be maintained. Money for competitive development programs is a prime target in a budget squeeze, and initial high-level support for competition may evaporate. In the services and in the OSD, there are frequent changes in top-level personnel. When new people take over, they inevitably change priorities. Written policy supporting competition remains fairly consistent, but

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capacity-utilization model uses industry-wide capacity as an input, however, rather than the capacity of an individual firm.

[13] See Michael D. Rich, *Competition in the Acquisition of Major Weapon Systems: Legislative Perspectives*, Santa Monica, Calif.: RAND, R-2058-PR, 1976.

interest in competition changes with personnel. The result is that it can be difficult to maintain all the funding necessary to conduct a competitive development program.

Competition can slow the program during EMD because of the time involved in testing and source selection or in qualifying a second contractor. Schedules also can lengthen because of the increased program complexity and increased bureaucratic involvement caused by competition. By lengthening schedules, competition carries the risk of raising program costs. Moreover, the risk of increased program length is also a disincentive to competition because there is usually a strong desire to deploy the system as rapidly as possible.

During the production phase the funding required to qualify a second, competitive source appears to pose less of a problem, at least for less complex systems or components. Perhaps this is because by the time the program is in production all major conceptual issues have long since been resolved, and attention is more easily focused on the task of efficiently producing the system. Furthermore, there is some belief that clear evidence of financial benefit exists for competitive reprocurement.

Extra Management Effort

Competition increases the workload of the Program Office. This extra work stems from two sources. First, if a competition is to be beneficial, considerable planning for the competitive steps is necessary. The request for proposal (RFP) must be prepared and the source selection process must be designed. The Program Office must comply with certain regulations designed to ensure the fairness of the competition. This process involves special security to deal with "competition sensitive" material, special reports, et cetera. Second, competition introduces the possibility of lawsuits, disputes, and charges of unfairness by contractors who lose. So, the source selection must be carried out in a way that not only chooses the best design, but also raises a minimum number of questions about fairness. That is not an easy task, particularly because little information or guidance can be drawn from the experience of other programs. "Lessons learned" reports from other programs are rarely useful. For the most part, program managers must plan based solely on their experience. Some program managers need no more then their past experience; however in other cases, the lack of experience with the additional burden complicates planning.

Competition during production introduces more management complications. Qualifying a second producer after production has begun can be a major effort. It is difficult and expensive to create a good technical data package (TDP) for the second contractor to use in starting production, and even more difficult to persuade the first producer to pass along to a competitor

the benefits of its manufacturing experience. The program manager can choose to develop his own TDP, but for major programs this is almost impossible. Not all services have in-house capability to evaluate a TDP, and without this capability, it is difficult to judge the adequacy of a TDP. Even with a good TDP, it frequently takes a major effort by the Program Office to help the second source through all its technical problems and into production.

Another source of additional work in developing a second source is that the Program Office must work with both contractors on such things as quality control and configuration management. It is generally quite difficult to get two contractors to produce systems and components with interchangeable parts. If they do not do so, the Program Office faces additional problems in spare parts procurement and logistics. Further, each added production line means an additional set of non-recurring costs whenever there is an engineering change. Finally, if two production lines are created, the program manager must decide how hard to push each contractor in order to ensure the benefits of competition. If the manager pushes too hard, he runs the risk of driving one of the contractors out of the program.

As we have seen, one factor in program managers' reluctance to introduce competition is the perception that it will make management of their program more difficult and increase their workload. Since very few program managers believe they have enough well-qualified people to cover the work of monitoring one source, they are reluctant to take on even more work or to complicate matters.

It should be noted that under special circumstances competition can reduce the management workload of a Program Office. Under a fixed-price development program where the prime contractor is obligated only to a "best effort," the program manager can adopt a largely "hands off" management style, with competition substituting for a host of conventional Program Office management controls over the contractors. However, this acquisition form is rarely used, the services preferring to retain considerable control over contractor actions even with the attendant management workload. Another possibility is for the prime contractor to act as the agent for the government in organizing competition for stipulated subsystems or components, thus relieving the Program Office of most of the burden of managing competition.

Few High-Confidence, Near-Term Benefits

Disincentives of the sort described above tend to limit a manager's enthusiasm for introducing competition. The costs of competition are short-term and clear, while the benefits are long-term and uncertain. The incentive structure is more likely to motivate the program manager to look for strategies that return short-term benefits. Apart from exhortations in policy

documents and the conventional wisdom that competition is good for everyone, few direct incentives for introducing competitive practices exist. A program manager is unlikely to be rewarded merely for introducing competition. Real cost reductions are difficult to prove and can be masked by other factors, such as inflation. Moreover, given a typical tenure of only about three years, a program manager is unlikely to be around to receive the credit for any benefits that finally accrue.

In many cases, competition is seen as impractical. There may be few or no contractors qualified to participate in a competition, and many of them may not wish to compete. Contractors often find that the uncertainties about how a competition will come out and the criteria to be used in the source selection are sufficient to deter them from entering a competition. Qualifying a second source can be seen as impractical because the production run is too small, the tooling for the second production line is too expensive, or the design is too complex to be transferable.

Outcome Is Uncertain

Retrospective studies of second-source procurement programs have not been conclusive, partly because their conclusions depend heavily on analytical methods used. A 1981 RAND study of the Shilelagh missile, for example, showed that analysts—by using different analytical procedures—could produce vastly different estimates of the effect that second-sourcing had on procurement costs. Those estimates ranged from a cost savings of 79 percent to a cost increase of 14 percent[14]. Some uncertainty is inevitable—if two sources are used, one cannot know the cost that would have been incurred with a single source only. That cost must be *estimated* and compared with the *actual* cost incurred through second-source procurement.

A follow-on to the 1981 report describes five methods of estimating the cost benefits of second-sourcing. For each method, we *estimated* the hypothetical single-source cost for four air-to-air missile programs (AIM-7F, -7M, -9L, -9M). For none of these programs were any of the five analytical methods unanimous in indicating that a net cost savings accrued to the government through competition. However, three of the five methods did show a net savings for two programs (AIM-7F and AIM-9L), and four methods did show a cost increase for one procurement (the AIM-7M).[15] In any case, it is exceedingly difficult to determine a distinct cost benefit for

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[14] K.A. Archibald, et al., *Factors Affecting the Use of Competition in Weapon System Acquisition*, Santa Monica, Calif.: RAND, R-2706-DR&E, 1981.

[15] J.L. Birkler, et al., *Issues Associated with Second-Source Procurement Decisions*, Santa Monica, Calif.: RAND, R-3996-RC, 1990.

competition. The path not taken is always an educated guess. When the results are very sensitive to the assumptions made, one must be cautious in drawing any conclusions.

4. COMPETITION DURING PRODUCTION: ANALYSIS APPROACH

This study's analytical framework approached the issue of competition in the JSF program from the perspective of a defense policymaker. It was designed to identify the types of information that policymakers would require and the kinds of tradeoffs they would encounter in order to make informed near-term and long-term policy decisions.

ANALYSIS PROCESS

Our first step in designing an analysis process was to outline the different ways that competition can be introduced into an acquisition program. In this study we found it useful to organize the analysis into four different categories of such competition, as shown in Figure 4.1. The most direct form of competition is to have two or more suppliers concurrently producing the system or some elements of the system. Another possibility for competition is through the availability of other similar systems that could be substituted for the item in question and that could perform at least most of the same military missions. For example, the later versions of the F/A-18 might be considered a competitor to the Navy version of the JSF. We identify these options of "within JSF Program" and "Outside JSF Program" in Figure 4.1.

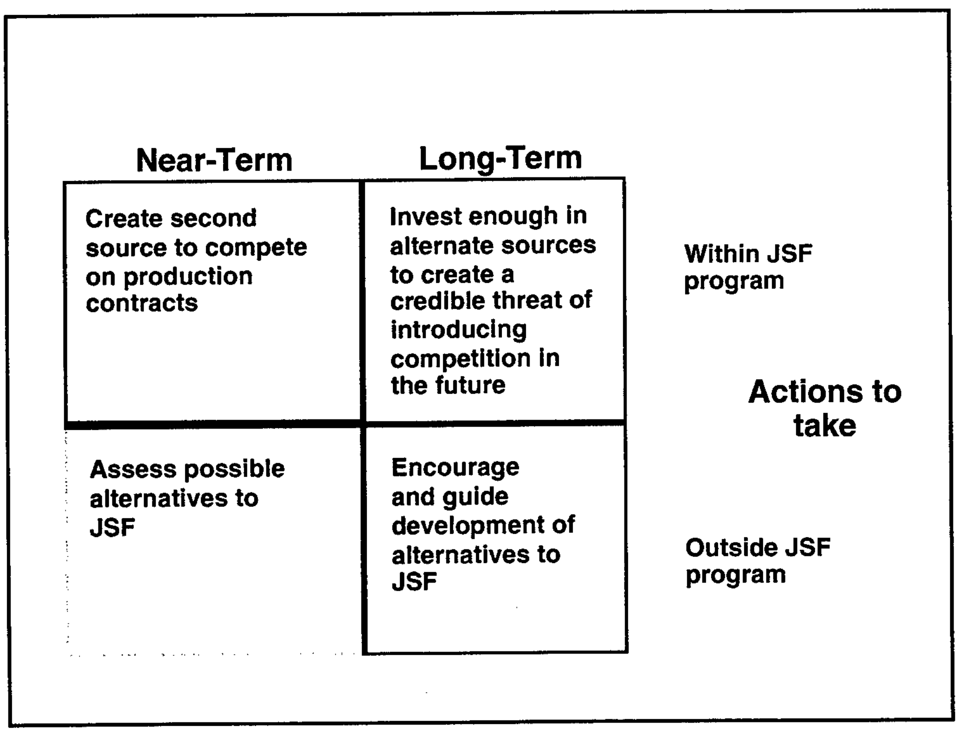

Figure 4.1—Near-Term and Long-Term Competition Options Within and Outside the JSF

Actions can be taken to implement these options in the near-term (e.g., the start of EMD) or at a later time (e.g., following LRIP or when an advanced series is introduced.) This study devoted most of its attention to near-term competition for production within the JSF program, while the other three options were examined in lesser detail.

OPTIONS FOR NEAR-TERM COMPETITION IN PRODUCTION

The introduction of a second source during production of a weapon system is expected to have a variety of both benefits and liabilities, and the balance can be judged on the basis of several different criteria. Furthermore, the process of examining and evaluating the outcome of the balance differs from one criteria to another. Thus, the overall evaluation of where and whether to introduce a second production source must entail several different analyses and the subjective combination of the individual measures.

In this JSF study we elect to examine the desirability of introducing near-term competition in production on the basis of two sets of criteria:

- Would competition be likely to reduce total ownership cost?
- Would competition be likely to have other benefits that cannot be easily expressed in terms of dollar cost?

Our approach to each is outlined below.

IS COMPETITION LIKELY TO REDUCE COST OF OWNERSHIP?

We first examined the issue of whether competition during EMD is likely to reduce acquisition cost. The most direct approach would be to estimate the cost for a sole-source producer, then estimate the cost for a pair of competitive producers, and compare the two. The first step is straightforward, using well-established historical data on aircraft production costs. Unfortunately, we have no comparable data or cost estimating relationships that would enable us to estimate production costs in a competitive environment.[16] What we do have is a limited amount of historical data showing the amount by which production cost changed when

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[16] There are no cases in the United States since the second world war where aircraft have been produced by competitive sources. In a few cases parallel production lines were established but the goal was to accelerate production, not to save cost.

competition was introduced into an on-going sole-source production program. To use this information we modified a strategy suggested by Margolis, et al:[17]

- Estimate the expected cost of producing the JSF by a sole-source producer, using JSF system characteristics and available cost estimating procedures;
- Estimate the additional costs of introducing a competitor, including the front-end investment plus the inefficiencies caused by each producer having a decreased production run;
- Determine the percent reduction in sole-source cost that would be required to offset the additional costs of introducing competition;
- Look to historical evidence on the distribution of production cost changes when competition was introduced as a basis for estimating the likelihood of achieving competition-induced cost reductions large enough to offset the additional costs incurred by introducing a second producer. (These data are described in the next chapter.)

The result is an estimate of the likelihood that the government would "breakeven" on the introduction of a competitive second source for producing the JSF. We do not estimate the "dollars saved" or the "dollars lost" as a result of introducing competition; instead we estimate the likelihood that the overall acquisition cost to the government would be about the same for either strategy. If the likelihood is high, the government might reasonably elect to introduce competition in the expectation of achieving other potential benefits (see below). Likewise, a low expectation of breaking even on production cost would discourage the government from introducing competition because the net dollar cost of production might increase enough to outweigh other possible benefits. The details of the analysis process, and the results, are presented in Chapter 5.

There is a plausible basis for expecting that under some circumstances a competitive production posture might lead to higher quality of the product, which in turn would be reflected in higher reliability and thus lower support cost throughout the operating life of the JSF. The available historical data do not permit a quantitative link between competitive production and product reliability so we are unable to estimate the magnitude of expected savings in terms of dollar costs. Instead we assume various levels of reliability improvement and estimate the likely

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[17] Milton A. Margolis, Raymond G. Bonesteele, and James L. Wilson, *A Method for Analyzing Competitive, Dual Source Production Programs*, presented at the 19th Annual DoD Cost

consequence in terms of reduced O&S costs, and then determine if such "reasonably expected" savings due to competitive production would alter the likelihood of breaking even on introducing a competitive production source. The exact process and results are described in Chapter 6.

ARE THERE OTHER BENEFITS THAT MIGHT BE EXPECTED FROM COMPETITIVE PRODUCTION?

The main emphasis of this study was on estimating the likelihood of breaking even on the cost of production as a result of introducing a competitive second source. However, we would be remiss if we ignored other possible consequences of competition. We made a cursory examination of five such consequences, and included the results in our overall evaluation of competition during production. The additional considerations we examined are outlined below. The first consideration lent itself to an examination, while we pursued the others in a qualitative manner.

- Would competition tend to mitigate the amount of cost growth that might be expected during development and production?
- Would competition strengthen the industrial base?
- Would competition tend to reduce overall risk levels in the program?
- Would competition enhance the rate of introducing technical innovations and the overall quality level of the product?
- Would competition affect the kind and scope of international participation?

The results of these secondary examinations are presented in Chapter 7.

Analysis Symposium, September 1985.

5. ANALYZING ACQUISITION COSTS

In the present study, we consider introducing a second contractor early in the JSF program as well as at some future, to be determined, time. Our primary focus is on what makes sense at the beginning of EMD, which should occur approximately a year after this study. For this study we have cost data from both of the demonstration competition contractors plus the JSF Program Office regarding the baseline "winner-take-all" program. The alternative is to introduce competition, for which there is no information.

Analyzing the effect of competition on acquisition costs is always complicated by the absence of data regarding the "path not taken." or the " path for which there is no data." The baseline is no competition and the alternative is introducing a second contractor at some point during the acquisition process. The second contractor will produce some number of units during the completion of the procurement program. Our approach employs a modification of a "breakeven analysis" technique that was developed several years ago specifically to handle "the path for which there is no information." The following section of this chapter describes this approach. The next section presents analytical results for several possible scenarios for implementing competition in the JSF program. The final section presents the findings of several studies regarding production cost savings, or losses, on past competitive programs, and discusses the use of these results to assess the likelihood that the JSF may be able to achieve savings under competition.

BREAKEVEN ANALYSIS

There is no reliable, quantitative method for estimating the magnitude of cost savings that may occur when a second source is introduced in a production program. To make such an estimate requires knowledge of, or assumptions regarding, the behavior of both the prime contractor and the second source under competition. What are their total business bases? What are their attitudes toward risk? Are they willing and able to reduce engineering or indirect staff to reduce costs? These, plus many other questions, would need to be answered.

We can, however, estimate the additional, non-recurring, costs of implementing a second contractor, and then deduce the recurring production savings needed to offset the additional cost. The implementation of this approach is a modification to the breakeven analysis suggested by

OSD/PA&E in 1985.[18] Breakeven refers to the condition where the cost to the government using two contractors is equal to the cost of using only the prime contractor. It is expressed by the relationship

$$TC_{ss}(Q,R) + INV_{ss}(R) = TC_1(q1,r1) + TC_2(q2,r2) + INV_c(r1,r2) \qquad (1)$$

Where:

$TC_{ss}(Q,R)$	=	Total recurring cost of the single-source contractor, to produce quantity Q at peak rate R, after competitive production begins
$INV_{ss}(R)$	=	Additional non-recurring cost to bring the single-source contractor to full production rate R
$TC_1(q1,r1)$	=	Total recurring cost for the original contractor, to produce quantity q1 at peak rate r1, after competitive production begins
$TC_2(q2,r2)$	=	Total recurring cost for the second contractor, to produce quantity q2 at peak rate r2, after competitive production begins
$INV_c(r1,r2)$	=	Non-recurring cost required to bring both the original and second contractors to their full production rates under competition
Q	=	q1 + q2

We can rewrite equation (1) as

$$TC_1(q1,r1) + TC_2(q2,r2) + INV_c(r1,r2) - TC_{ss}(Q,R) - INV_{ss}(R) = 0 \qquad (2)$$

If the two competing contractors behave as the prime would as a sole source, then this expression is expected to be greater than zero. INV_c will be greater than INV_{ss} because there are additional costs to establish the second contractor. The second source must have sufficient tooling, it must be qualified to produce the end item, it has its own set of overheads, and so on. The production costs for the two "competing" contractors will be greater than the total cost for the original contractor as a sole source, if the two contractors follow the same improvement curve as the sole source does, because of "loss of learning" (LoL). The only way that equation (2) can equal zero is if the competing contractors' behaviors change to reduce the sum of the first two

[18] Ibid.

terms below what would be obtained if they followed the sole source's production cost improvement curve.

For the present study we requested estimates from both prime contractors as well as the JSF Program Office regarding the two sole-source teams. These data provide the basis for determining TC_{ss} and INV_{ss} the cost of establishing the dual-source arrangement using the non-recurring cost data for the sole source. We calculate the cost for the two contractors to each produce one-half of the total quantity using the sole-source contractor's improvement curves.[19] We then calculate the ratio of the left side of equation (2) to the total production cost for the sole source to produce the entire quantity. This is the percent by which the net cost of the two sources exceeds the sole-source production cost when the two sources do not change their production cost behaviors relative to the sole source. Expressed another way, it is the percent decrease relative to the sole source's production cost that must be achieved for the two competitors to offset the loss of learning and the additional start up costs of the second firm.

$$RCR = [TC_1(q1,r1) + TC_2(q2,r2) - TC_{ss}(Q,R) + INV_c(r1,r2) - INV_{ss}(R)] / TC_{ss}(Q,R) \quad (3)$$

To simplify reference to this expression in the remainder of this report, we refer to it as the required cost reduction (RCR). As shown, Equation 3 yields the Net Savings required to cover both the loss of learning and the investment costs of establishing the dual production sources. If the two INV terms are deleted from the expression, the result is the Gross Savings or the recurring cost savings.

JSF PROGRAM RESULTS

There are two ways that competition can be structured in the production phase of a weapon system. A useful outline is shown in Table 5.1. We assume that a basic design has been established by the prime contractor, a series of vendors established for the major sub systems, (landing gear, ejection seat, gun, etc.) and for the Mission System components, and that the prime has set up a factory for Final Assembly and Check-out (FACO). Each of these activities can also be performed by a second source, and in principle that second source can produce the various components and functions in either or two ways. It can build the system element using the exact design created by the prime contractor or the prime's vendor ("Build-to-Print"–BTP) or the

[19] The recurring cost calculations do not account for production rate effects. The non-recurring costs for the two competing contractors are determined based on a peak rate of two-thirds of the sole-source rate.

second source can design and manufacture its own version of the system element so that it can be directly integrated into the overall system design ("Form-Fit-Function"–FFF).

Table 5.1

Options for Second Source Participation During Production

System Element	Method Employed by Second Source: Build-to-Print	Form-Fit-Function
Airframe Structure	+	-
Major Sub-Systems	+	+
Mission System Components	-	+
Final Assembly & Check-out	?	?

Which of the different second-source strategies are more or less appropriate and widely applied varies with the system element, as indicated by the (+) and (-) symbols in the table. For major structure assemblies it is most common for the second source to build to print; it is generally impractical to have different structure designs intermixed in a vehicle. However, for many subsystems and for mission system components it is sometimes practical and desirable for the second source to create its own design in such a way that it can be inserted into the basic vehicle and function just like the original (prime's vendor) design. Finally, if the second source also sets up a production line for final system assembly and check-out, the detail tooling and testing methods might be similar or different from that of the prime, depending on detail characteristics of the system.

The distinction between BTP and FFF is important because the cost of establishing a second source is significantly different for the two strategies. The FFF option usually incurs greater start-up cost because of the additional design, development and test effort required, but sometimes that additional cost is justified through introduction of lower fabrication costs or achievement of improved performance compared with the original design.

Specific Cases Examined

Data provided by Boeing, Lockheed Martin and the JSF Program Office (JPO), combined with data available within RAND, permitted us to analyze each of the elements shown in Table 5.2.

Table 5.2

Airframe and Mission System Components in RAND Study

Airframe Structure	*Airframe Subsystems*	*Mission System Components*
Forward Fuselage	Landing Gear	Radar
Center Fuselage	Ejection Seat	Electronic Warfare/Countermeasures
Aft Fuselage		Communication Navigation/Identification
Tail Surfaces		Electro-optical
Control Surfaces and Edges		ICP
Wing		Distributed IR Aperture System
Final Assembly and Check Out		Targeting FLIR

We also analyzed the complete mission system suite and the complete airframe (including subsystems). The JSF engine is already under competition and is not addressed in this study.

PRODUCTION COST SAVINGS REQUIRED

Ground Rules and Assumptions

We determined the RCR for each of the system elements listed in Table 5.2. For each case we considered both a "Build-to Print" and a "Form-Fit-Function" option. For Build-to-Print (BTP), it is assumed there is only one design that is produced by both contractors. For the Form-Fit-Function (FFF) calculations, it was assumed that each contractor could provide its own design that could be integrated into the total weapon system and satisfy all weapon system requirements.[20] For all analyses, we assumed the quantity is divided evenly between the two competing contractors ($q1 = q2 = Q/2$)[21], that the competitive contractors are facilitized to produce at a peak rate that is 2/3 of the sole source peak rate ($r1 = r2 = R*2/3$), and that competition begins with the first units produced following EMD.

For all analyses, costs are in constant FY1994 dollars (JSF program base year).

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[20] While this is not a realistic assumption for many of the cases examined (see Table 5-1) it provides an extreme boundary for the costs of establishing the second source.

[21] A fifty-fifty split was selected because it results in the greatest loss of learning.

The baseline sole source costs are developed from the JSF Program Office's assessment of the contractors' costs to produce 3,002 aircraft. The JSF Program Office provided estimates for functional cost elements, labor and material. RAND adjusted these to create a set of composite aircraft costs.

Aircraft and mission system equipment quantities produced during EMD are shown in Table 5.3. The "Equivalent Number Built During EMD" is used to determine the cost improvement effects achieved during production of items and components during EMD and is not necessarily the number of complete systems produced. The right-hand column shows the cost improvement curve slopes used in the breakeven calculations.

Table 5.3

EMD Equivalent Quantities and Improvement Curve Slopes Used in the Analysis

System	*Item*	*Equivalent Number Built During EMD*	*RAND Cost Improvement Curve Slope (%)*
Airframe Structure	Conventional Takeoff and Landing Airframe	6	79
	Carrier variant airframe	5	79
	Short takeoff/Vertical Landing Airframe	5	79
Mission System Components	Radar	11	88-93
	Communication/Navigation/Identification	11	89–93
	Electronic Warfare	11	89–93
	Distributed Infrared Aperture System	11	85–91
	Targeting Forward-Looking Infrared	11	85–91
	Integrated Core Processor	21	90–95
	Controls & Displays	21	85–93
	VMS	21	88–93
	SMS	16	89–93

For all airframe sections and variants, cost improvement curve slopes were assumed to be 79 percent for manufactured items and 92 percent for purchased items. Slopes for all mission systems were developed by RAND, with the ranges indicating uncertainty in the estimates for a high and low estimate. All slopes were assumed to be constant throughout the production runs (3,002 aircraft for the sole source case and 1,501 each for the dual source case). For FFF cases, the second source was assumed to produce the same number of EMD units as the prime. Both start production at the same improvement curve position. For BTP cases some learning is assumed to transfer from the prime plus the second source builds two qualification units. Thus, with these

two factors, both competitors are assumed to start from the same point on the learning curve for each component or section.

For FFF cases, the second source's EMD costs were assumed to equal the prime's EMD costs.

For BTP cases, a more detailed estimate was made for second source costs. For mission systems components, the second source non-recurring hardware development cost was assumed to be 50 percent of the prime's cost. The second source is also assumed to incur 20 percent of the prime's software development cost. For airframe sections, the second source's EMD costs are estimated as shown in Table 5.4. We assumed the prime would build twelve aircraft in EMD. (The quantities shown in Table 5.3 do not represent complete aircraft.)

Table 5.4

Estimating Assumptions for Second Source Airframe EMD Costs Under BTP Scenario

Cost Element	*Factor (% of Prime's Costs)*	*Rationale*
Non-recurring Engineering	25	Covers translation of production methods, process, etc., plus representation on appropriate IPTs.
Non-recurring Tooling & Tooling Quality Control	34	Facilitates both contractors to produce at 2/3 of the sole source peak annual rate
Subcontract	10	Covers design translation for vendors plus representation on appropriate IPTs
Non-recurring Purchased Equipment	19	Equivalent to first two of 12 units assuming 92% slope
System Test	26	Equivalent to first two of 12 units assuming 79% slope
Ground Test	5	Assumes second source participates in IPTs but its two test articles do not require static and fatigue testing
Mockups	0	Digital, 3-D data base
Flight Test	17	2/12
Operational Test & Evaluation	17	2/12
Survivability Test	0	No live fire for BTP items
Systems Engineering/Program Management	25	Directly proportional to non-recurring engineering
Support & Training	34	Facilitates both contractors to produce at 2/3 of the sole source peak annual rate

Rate tooling costs were determined by allocating the JSF Program Office's estimate for total rate tooling cost ($1,500M) between airframe ($1,200M) and mission systems ($300M). This allocation is based on F/A-18E/F actuals. These values were further allocated to sub-elements, using contractor data.

RESULTS

The RCRs for the airframe sections for BTP and FFF are shown in Table 5.5. The comparable results for the mission system components are shown in Table 5.6. The ranges in Table 5.6 reflect the improvement curve ranges shown in Table 5.3.

Table 5.5

Airframe Component Breakeven Estimates

Airframe Element	BTP	FFF
Center Fuselage	30%	46%
Aft Fuselage	28%	39%
Tail Surfaces	30%	49%
Wing	32%	54%
Edges	27%	33%
Landing Gear	30%	45%
Ejection Seat	31%	51%
Final Assembly and Check Out	26%	27%
Complete Airframe	30%	46%

Table 5.6

Mission Systems Component Breakeven Estimates

Mission System Component	BTP	FFF
Radar	14–20%	23–29%
CNI	15–20%	26–31%
EW	12–16%	18–22%
ICP	16–21%	34–40%
DIRS/DAS	14–22%	23–30%
TFLIR/EOTS	19–27%	34–41%
C&D	19–23%	34–38%
SMS	15–20%	30–35%
VMS	14–18%	28–32%
Complete Mission System	14–20%	25–31%

The values in these figures are based on undiscounted costs to facilitate comparison with the historical experience as discussed below.

PAST EXPERIENCE WITH INTRODUCING COMPETITION IN PRODUCTION

To evaluate the likelihood of achieving the RCR, we turn to historical experience. The four-month schedule for this project did not allow us time to collect all the source data used in past studies and redo the cost savings analyses on a consistent basis. Consequently, we were limited to gathering those studies and analyzing the results they presented.

There have been several studies of competition in procurement conducted over the past 30 years, but the most recent ones were completed early in the 1990s. The studies used are listed in the bibliography. The historical studies cover a wide variety of weapon systems and elements thereof.

To support our analyses of the JSF program, we treat the electronics equipment separately because they are the most similar to the mission system equipment, and they typically have much shallower cost improvement slopes than major hardware systems. We group all other historical data together for comparison to the airframe elements.

The analytical methods used in the referenced studies are varied and in many cases are not consistent. Some compared the first competitive buy to the last non-competitive buy. Some compared the competitive buys to the total of all buys. Some compared the competitive buy to a projection of the non-competitive experience for the same quantity. In some cases, savings were calculated only for the completed buys while others projected to the completion of the program (as envisioned at the time of the study). Some used cumulative average learning curves and others used unit learning curves. A couple of them made adjustments for economies of scale (capacity utilization, production rate). A few used discounting, but the rates were not always specified. Some calculated gross savings and others included nonrecurring costs for establishing the second source, but they did not always include the same set of nonrecurring costs. The documentation was not always clear regarding these points.

There are significant variations in the programmatic backgrounds of the programs. Competition was implemented on several programs because the customer was not satisfied with the original contractor's performance. In some cases, cost was believed to be too high but there were also instances of poor product quality or reliability. Also, the programs differed in the timing of the start of competition. Numbers are not available for all programs, but for twenty

competitive split-buy programs the quantity produced by the prime contractor prior to competition ranged from a low of 4 percent of the total to a high of 87 percent of the total.

Historical data used here were taken from IDA-79, TASC-79, SAI-82, NPS-83, RAND-83, NCCA-89, and RAND-90b (see bibliography). Data from these sources appears to be generally methodologically consistent. The savings are based on actual costs or projections to the end of the program (not first competitive lot compared to last non-competitive lot). The data are all undiscounted and are based on gross savings.

There is some overlap between these studies in weapon systems analyzed. Tables 5.7 and 5.8 present the highest and lowest production with savings reported in the historical documents. If a weapon system was included in only one study, the high and low values are the same. Table 5.7 presents production cost savings for the non-electronics items. Table 5.8 shows similar results for the electronics items. Most of the non-electronics items are ships or missiles. The electronics are mostly radios and simple components.

Table 5.7

Estimated Cost Savings from Competition in Missiles, Ships, Etc., Programs (%)

Missiles, Ships, Etc.	*Low*	*High*	*Count*
Dragon—round	2.8	2.8	1
F404	5.1	5.1	1
TAO 187	5.1	5.1	1
LCAC	8.2	8.2	1
VLS canisters	9.4	9.4	1
AIM-54C—G&C	11.0	11.0	1
Dragon—tracker	12.3	12.3	1
VLS launcher	16.1	16.1	1
Mk 48 torpedo	16.3	16.3	1
CG 47	19.6	19.6	1
Std Missile 2—G&C	20.6	20.6	1
Tomahawk	20.7	20.7	1
Std Missile 2—motor	23.9	23.9	1
LSD 41	28.3	28.3	1
Bullpup—Martin	31.7	31.7	1
Std Missile 2 (RIM-67A)	34.0	34.0	1
AIM-9D/G	-71.3	0.7	4
Mk 46 torpedo	-36.4	-30.9	2
AIM-9M	-35.4	12.7	5
AIM-7M	-28.6	5.3	5
AIM-7F	-25.0	9.0	7
Rockeye	-23.0	25.5	4
Shillelagh	-8.0	9.4	4
Std Missile 2 (RIM-66A)	-4.2	59.2	3
AIM-9L	-3.8	24.0	5
TOW missile	8.9	26.0	5
Mk 48 torpedo—electronic assy	11.6	47.0	2
Bullpup—Combined	18.7	26.5	4
Hawk—motor parts	19.9	49.9	3
Mk 48 torpedo—warhead	23.7	48.6	2
TOW launcher	30.2	44.2	2

Table 5.8

Estimated Cost Savings from Competition in Electronics Systems and Equipment Programs (%)

Equipment	Low	High	Count
AN/ARC-131 Radio	-16.1	-16.1	1
SPA-66 Radar Indicator	-3.4	-3.4	1
PP-4763/GRC Power Supply	0.5	0.5	1
Aerno 60-6042 Elec Cont Amp	8.5	8.5	1
AN/ASN-43	10.7	10.7	1
UPM-98 Test Set	11.5	11.5	1
FAAR Radar	16.6	16.6	1
FAAR TADDS	18.2	18.2	1
AN/SGS 23 208A Transducer	32.3	32.3	1
PRT-4	42.3	42.3	1
AN/FYC 8X	43.2	43.2	1
AN/ARA-63 Radio Receiver	57.9	57.9	1
FGC-20 teletype	4.0	39.9	3
Aerno 42-2028 Generator	7.3	19.9	2
APX-72 Airborne Transponder	9.4	27.1	3
SPA-25 Radar Indicator	10.7	48.8	3
AN/GRC-103	11.9	60.1	3
TD-660 Multiplexer	14.2	38.3	3
AN/PRC-77 Manpack radio	20.5	41.9	3
MD-522 Modulator	25.9	58.6	3
Aerno 42-0750 Voltage regulator	29.2	54.8	2
TD-204 Cable Combiner	35.5	62.1	3
TD-352 Multiplexer	36.0	58.0	3
U.S.M-181 Telephone Test Set	36.3	56.0	2
TD-202 Radio Combiner	36.5	46.8	3
CV-1548 Signal Converter	40.2	64.0	3
AN/GRC-106	41.8	43.3	2
60-6402 Electric Control	49.4	52.7	2
AN/ARC-54	55.0	63.1	2
MK-980/PPS-5	56.0	66.5	2
AN/APM-123	61.2	67.7	2

There were eight studies for the non-electronic systems. One of those eight (RAND90b) presented five alternative sets of results. The largest number of savings estimates was seven

(AIM-7F). There were 16 items with only one estimate. There were three studies for the electronics items. Twelve items had only one estimate.

Scatter diagrams of the high and low savings estimates from Tables 5.7 and 5.8 are shown in Figures 5.1 and 5.2, respectively. The points having only one observation are shown as filled circles. The points with multiple observations are open squares.

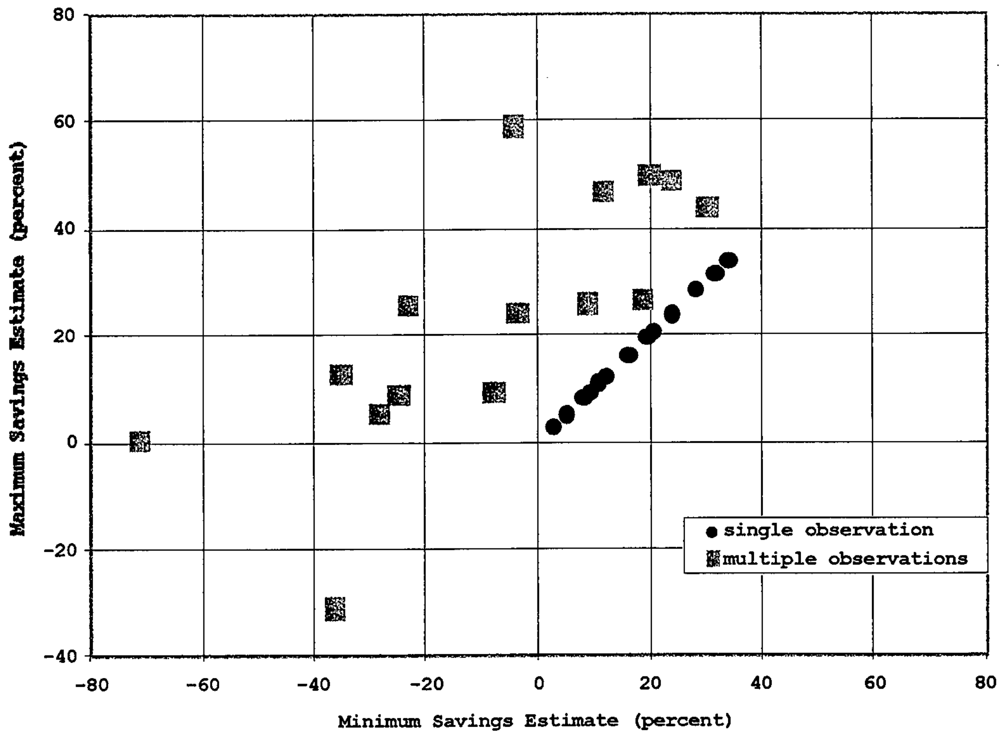

Figure 5.1—Maximum/Minimum Estimates of Savings from Competition in Missiles, Ships, and Related Programs

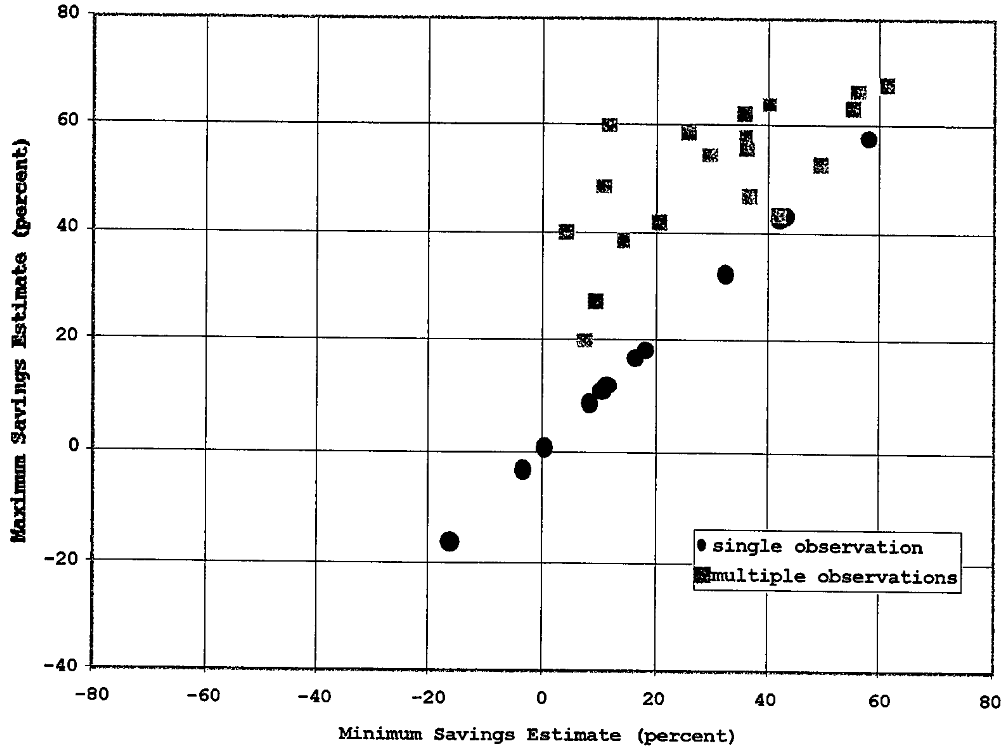

Figure 5.2—Maximum/Minimum Estimates of Savings from Competition in Electronics Programs

To assess the likelihood of obtaining different levels of savings we counted the number of points for which the minimum savings estimates were greater than 40 percent, 30 percent, 20 percent, 10 percent and zero percent. The results are summarized in Table 5.9.

Table 5.9

Fraction of Programs Examined that Achieved Savings

Savings Achieved (%)	*Missiles and Ships*	*Electronics*
>0	7/10	9/10
>10	5/10	8/10
>20	3/10	6/10
>30	1/10	5/10
>40	Nil	3/10

Relating these data to the JSF RCRs presented above requires some additional insight and interpretation. Relative to Equation (3) the historical production cost savings (HPCS) is represented by

$$HPCS = [TC_{1A}(q1,r1) + TC_{2A}(q2,r2) - TC_{ss}(Q,R)] \;/\; TC_{ss}(Q,R), \tag{4}$$

where the "A" subscript indicates the values are "actuals" or are projected from some actual data.

There are differences between Equation (3) and Equation (4) that are critical to the ability to use the historical data to judge the likelihood of achieving the required savings indicated by Equation (4). Most obvious, *Equation (4) does not contain any terms relating to investment costs.* As noted above, the historical studies varied in the fidelity with which they incorporated such costs. Furthermore, all the historical programs are BTP and have some amount of sole-source production prior to competition. In RAND's analyses, the second contractor participates in the program from the start of EMD, in both BTP and FFF scenarios, and begins production at the same time as the original contractor. This is assumed to eliminate the risk that the second contractor will not begin production on the same basis as the original contractor. It is also expected to cost more than setting up a second source after prior production by the original contractor. We omit investment costs from the historical data because they are not consistent with the basis for the required investment costs in our JSF scenario. Instead, we look for savings, as indicated by Equation (4), to help offset the required JSF investment cost.

The difference between $TC_{1A} + TC_{2A} - TC_{ss}$ in Equation (4) and $TC_1 + TC_2 - TC_{ss}$ in Equation (3) is critical, and subtle. A zero value for HPCS indicates that *all recurring cost consequences* of switching to two sources have been exactly offset through actions taken by the

two competing contractors.[22] These consequences include loss of learning as well as production rate or business base effects on both direct and indirect costs. As used in this study, $TC_1 + TC_2 - TC_{ss}$ in Equation (3) represents only the loss of learning resulting from competition. It does not include any of the other recurring cost consequences. Thus, these terms also have inconsistent definitions. Furthermore, we do not know the magnitude of the recurring cost consequences for any of the historical programs. From the sources available to support this study, we don't even know the quantity split between the leader and the follower. For the JSF analyses, we have no estimates for recurring cost consequences other than loss of learning, and we have calculated the loss of learning based on a 50:50 quantity split, arguably the worst case. The question is, what are the magnitudes of the missing values. We assume that the "rate" effect is the same (in percentage terms) for both cases and eliminate it from consideration. We also assume that the "rate" effect covers all the recurring cost consequences other than loss of learning. Thus we only need to address the amount of loss of learning present in the historical data.

Two of the historical studies[23] present quantity and improvement curve slopes that permit calculation of loss of learning for 20 programs. These documents provide the quantity produced before competition and the quantity produced competitively. They do not indicate the split between the contractors during competition. To estimate the loss of learning recovered by these historical programs, we assume the split is 50:50. We also assume that both contractors continue on the original contractor's improvement curve. The maximum loss of learning is 15.0 percent and the minimum is 0.1 percent. The average is 6.6 percent. Incorporating a 6.6 percent shift to the historical gross savings realized results in a slight improvement in the fractions of programs that achieved savings plus covered the nominal loss of learning. The results are shown in Table 5.10.

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[22] A negative value for HPCS indicates that savings beyond those required to offset recurring cost consequences have been generated. These savings are available to offset the additional investment costs of establishing competition. A positive value for HPCS indicates that the contractors did not offset the recurring cost consequences.

[23] APRO-78 and RAND-83.

Table 5.10

Fraction of Programs Examined that Achieved Savings and Covered Nominal Loss of Learning

Savings Achieved (%)	*Missiles and Ships*	*Electronics*
>0	8/10	10/10
>10	7/10	9/10
>20	4/10	7/10
>30	2/10	5/10
>40	Nil	4/10

The JSF airframe RCRs for the BTP option, as shown above in Table 5.5 are displayed graphically in Figure 5.3. The required cost savings values cluster around 30 percent. The airframe FFF option RCRs are shown in Figure 5.4. Only the FACO option is near 30 percent. The others range from about 35 percent to about 55 percent, averaging over 45 percent. The historical record indicates that roughly half the non-electronic systems achieved slightly less than a 20 percent savings from competition. This is indicated by the green bar in the figures. Thus, the likelihood of achieving the necessary savings for the airframe cases does not appear good.

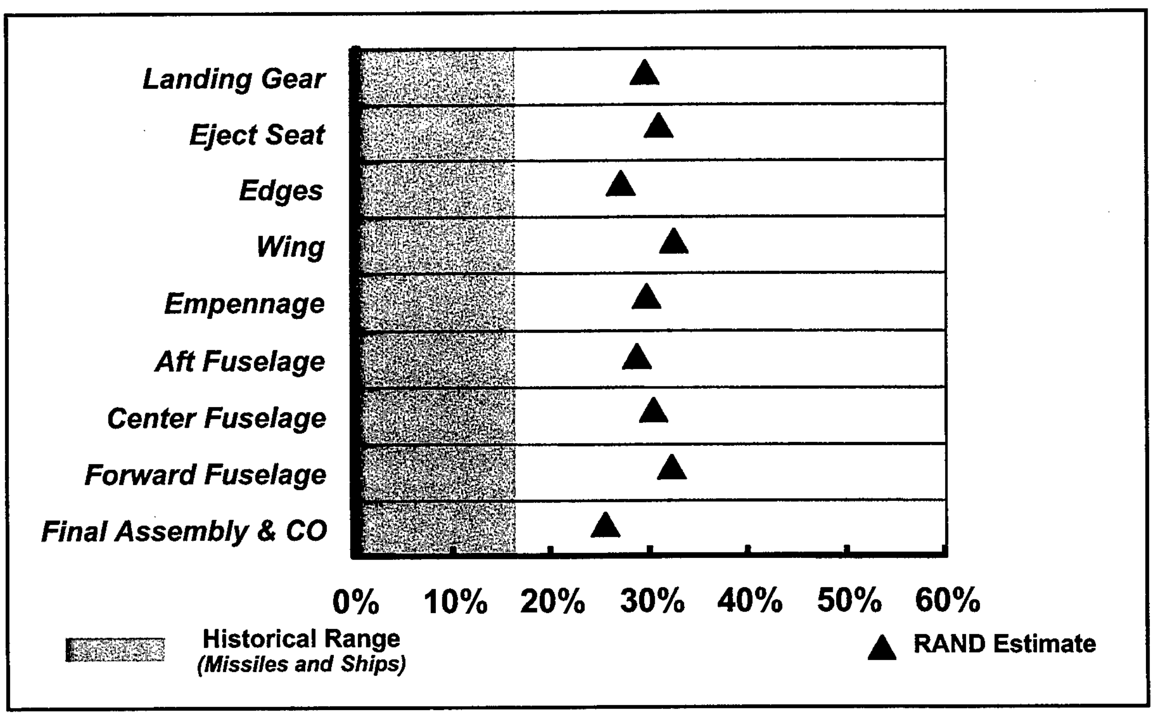

Figure 5.3—Airframe Component Breakeven Estimates (Build-to-Print)

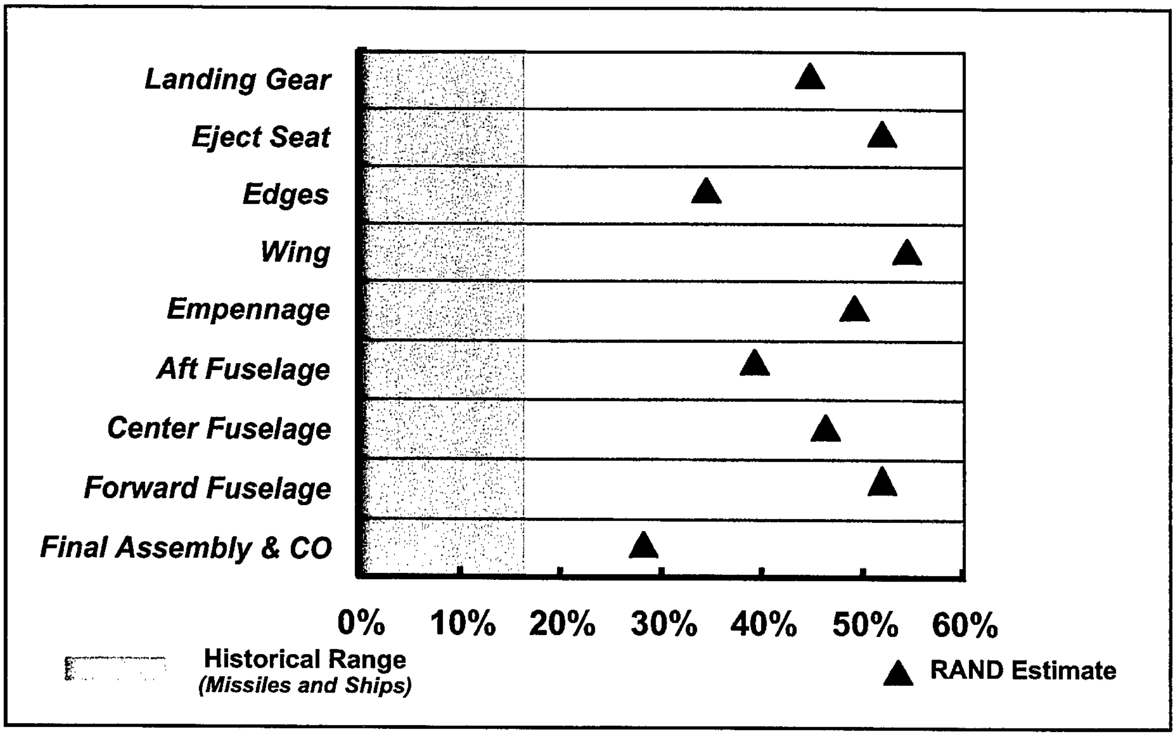

Figure 5.4—Airframe Component Breakeven Estimates (Form-Fit-Function)

The JSF mission systems RCRs for the BTP option, as shown above in Table 5.6 are plotted in Figure 5.5. The values range from about 15–25 percent. For the FFF option (see Figure 5.6), they range from a low of about 20 percent to a high of about 40 percent. These values are lower than the airframe values because the cost improvement slope for electronics equipment are shallower than for airframe elements. Table 5.10 indicates that approximately half of the electronics equipment systems achieved a 30 percent savings. The mission systems cases appear to be much more favorable.

However, the analyses represented in this study are all based on the projection of a production run of 3,002 identical aircraft (excepting the three service variants). Hence the competing contractors have 1501 aircraft each over which to achieve sufficient savings to recover the extra investment costs plus the loss of learning. The pace of evolution of avionics technology is much greater than that for airframe technology. While it is likely that there will be little change in the airframes for the 3,002 aircraft, it is highly likely that the mission system equipment will have one or more major variations. If there is a major avionics upgrade after the first 1,000 aircraft are produced, then the extra investment costs and the loss of learning (for only 1,000 units) would have to be recovered over the first 1,000 units. This would roughly double the RCR

needed to breakeven, thus significantly reducing the likelihood of being able to achieve adequate savings for the mission systems equipment.

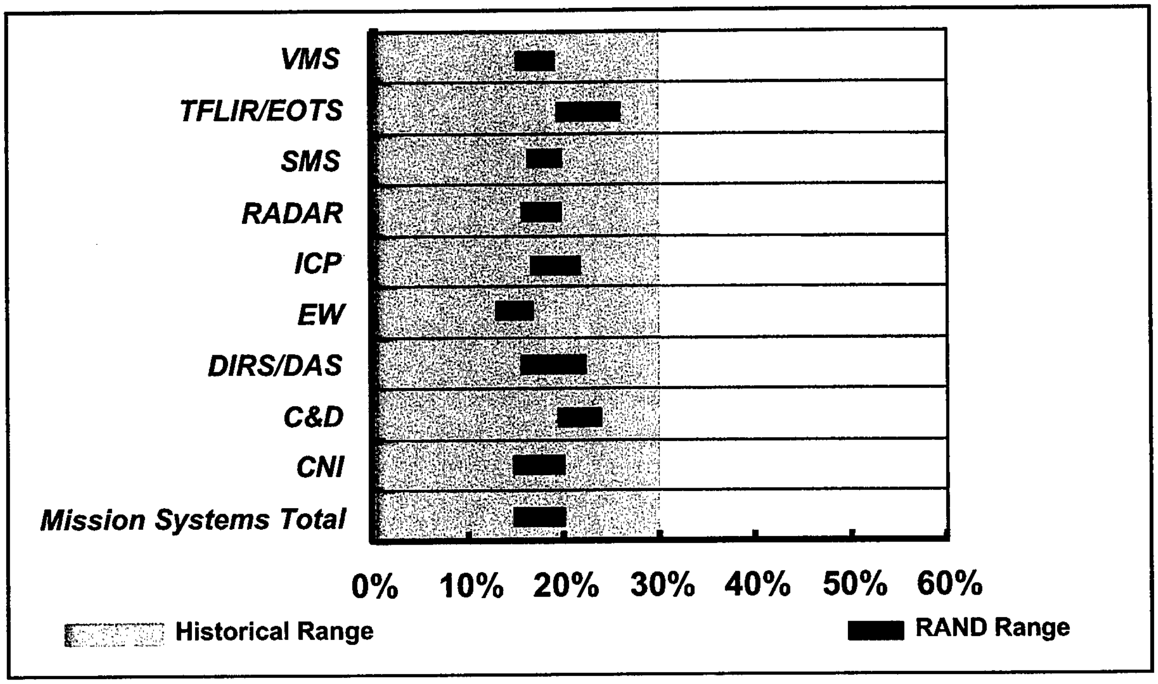

Figure 5.5—Mission System Breakeven Estimates (Build-to-Print)

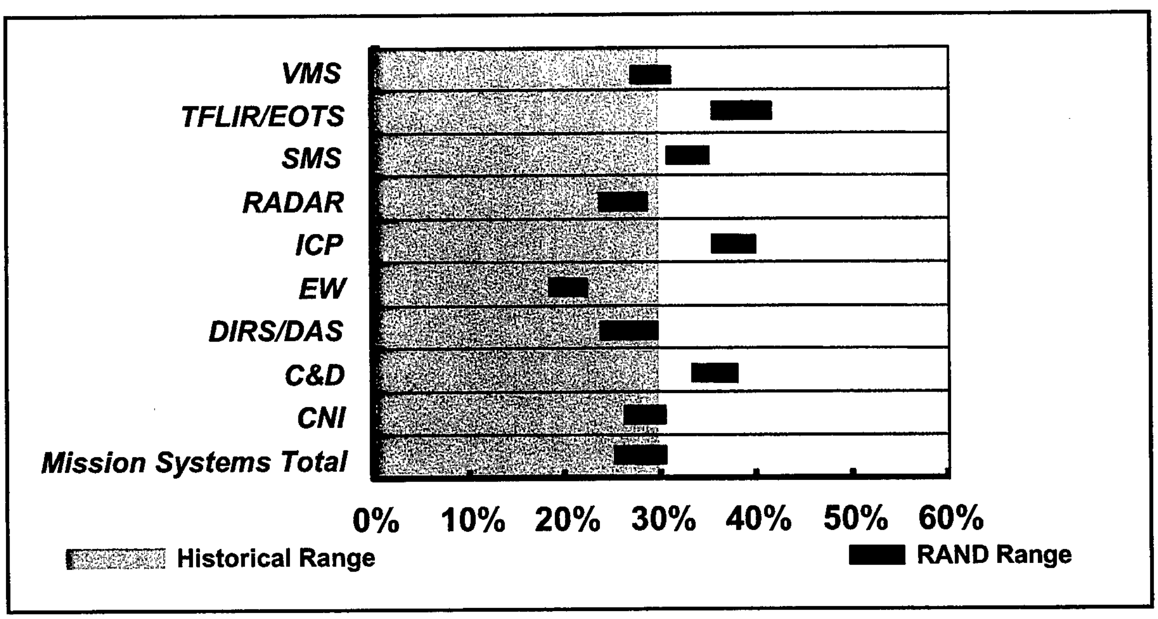

Figure 5.6—Mission System Breakeven Estimates (Form-Fit-Function)

6. ANALYZING OPERATING AND SUPPORT COSTS

Competition during EMD and production can result in beneficial effects on operating and support (O&S) costs. History suggests that competition can lead to a better design and to higher quality control during production, both of which should lead to higher reliability during field operations.[24] Higher reliability should lead to some reduction in O&S costs. We therefore need to examine the extent of possible competition-induced reductions in O&S costs and see if such reductions might be large enough to affect our estimates of the likelihood of breaking even by introducing a second-source producer.[25]

ANALYTICAL APPROACH

Our analysis followed four steps.

- First, we identified the elements of O&S cost that are likely to be affected by contractor actions during EMD and production in a typical military aircraft program. This was done by reviewing the categories by which O&S costs are typically reported and making judgements as to which of those would be likely to change as a result of changes in system reliability.
- Second, we determined the magnitudes of those competition-sensitive O&S costs in the JSF, as currently estimated for its projected operational life. Those data were provided to us by the JSF Program Office.
- Third, we calculated the sensitivity of those competition-sensitive O&S costs to changes in reliability. Those estimates were made by NAVAIR using the JSF O&S cost estimation model. That yielded a range of possible savings resulting from competition during production, expressed as a percent change in JSF O&S costs.
- Finally, we used those savings to adjust the break-even calculations reported in the previous chapter to determine whether the projected O&S cost savings led to a significant change in the overall likelihood of breaking even.

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[24] An example frequently referenced is the great engine war, which pitted Pratt & Whitney versus General Electric to produce a more reliable version of the F-100 engine.

[25] Competition in production might also lead to lower cost for replacement parts. However, analysis of lower spare parts costs requires a level of detail in O&S estimates that was not available at the time of this study.

Figure 6.1 presents our assessment of the degree of contractor influence on the major categories of O&S cost in a typical fighter aircraft program. We categorized the degree of influence into three values of high, medium, and low. The assessment reflects the judgment of personnel experienced in how the maintenance organization and process works. We judged only a few categories to be highly sensitive to changes in system reliability and, therefore, likely to be sensitive to the actions taken by the system producers.

	Contractor Influence			Percent of JSF
	High	Med	Low	O&S Cost
MISSION PERSONNEL				23
Officers			◆	
Enlisted		◆		
Civilians		◆		
UNIT LEVEL CONSUMPTION				45
POL		◆		
Consumable Supplies	◆			[9]
Depot Level Reparables	◆			[21]
Training Munitions			◆	
INTERMEDIATE MAINTENANCE				3
Officers			◆	
Enlisted		◆		
Civilian		◆		
Contractor		◆		
Consumable Material/Repair Parts		◆		
DEPOT				8
Aircraft Overhaul				
Airframe	◆			[5]
Engine	◆			
Support Equipment Repair	◆			
SUSTAINING SUPPORT				10
Support Equipment Replacement		◆		
Modifications		◆		
Sustaining Engineering Servicecs		◆		
Software Maintenance		◆		
Simulator Operations			◆	
Technical Publications			◆	
INDIRECT SUPPORT				12
Specialty training			◆	
PCS			◆	
Military medical care			◆	
Installation Support			◆	

Figure 6.1—Contractors Have Varying Influence Over Costs

We concluded that contractors have the highest level of potential influence over O&S costs in five areas—unit-level consumable supplies, depot-level reparables, airframe overhauls, engine overhauls, and support-equipment repair. Figure 6.1 shows our estimates of the percentages that those elements represent of the current O&S cost projections for the JSF, as provided by the JSF Program Office.

First, let us define what activities are included in each of these areas. Unit level consumption consists of fuel and energy resources; operations, maintenance, and support materials consumed below the depot organizational level; reimbursement of stock fund for depot level reparables (spare parts); operational munitions expended in training; transportation of materials, repair parts and reparables between the supply or repair point and unit; and other unit level consumption costs such as purchased services for equipment lease and service contracts. Consumable supplies are those items purchased for one time use and which are discarded when they must be replaced on an aircraft, such as filters, oil, etc. Depot level reparables are spare parts which, when removed from an aircraft, are tracked individually by an item number and returned to a central maintenance facility for repair and reuse. Depot maintenance is defined as personnel, material, overhead support, and depot-purchased maintenance required to perform a major aircraft or engine overhaul, and maintenance of a weapon system, its components, and support equipment at DoD centralized repair depots, contractor repair facilities, or on site by depot teams.

Our assessment that these areas could be highly influenced by the weapon system contractor is driven by the fact that the design and selection of airframe subsystems (and their inherent reliability) is part of the design responsibilities and activities that occur during development. High reliability aircraft, which are designed to be flown often with little or no maintenance between flights, should require less consumable supplies and fewer repair parts. We did not include service maintenance personnel in the "high" category of contractor influenced O&S costs. The costs were omitted because maintenance manning at operational units is not strictly a function of aircraft repair frequency, but rather, is set by individual Services using a host of factors. High reliability weapon systems should reduce, theoretically, the need for maintenance personnel. Depot maintenance is also driven by the contractor-controlled airframe design and the need for periodic overhaul at centralized maintenance facilities. To the extent the basic airframe design either obviates or reduces overhaul and major periodic maintenance, O&S costs can be reduced compared to historical systems. The design of an aircraft can reduce the amount of support equipment required to operate and maintain the aircraft, and higher reliability built into the support equipment itself can reduce the need to repair these items. Finally, the

weapon system contractor, if given responsibility for centralized repair of the aircraft and support equipment, can have a major influence on the cost of recurring repairs, even on highly reliable equipment.

The value for Aircraft Overhaul typically include the engine. Because our study excluded the engine, we adjusted the value to reflect only the airframe, mission system, and support equipment repair. Figure 6.2 shows the percentages of O&S costs for consumables, depot-level reparables and depot overhaul for just the airframe, mission system components, and support equipment repairs. The relative cost of depot overhaul for mission system and support equipment is small compared to the airframe and engine (in the range of 5% or less of the airframe estimated cost). Note that these values are for the total airframe and the complete mission system; data were not available to do this analysis for the same level of detail as the production cost RCR analysis above.

	Percent of O&S Costs	
	Airframe	***Mission Equipment***
Consumables	**~7%**	**~1%**
Depot-Level Reparables	**~6%**	**~7%**
Overhaul	**~5%**	

Figure 6.2—Percent of Airframe and Mission Equipment Operations and Support Costs Represented by Consumables, Depot-Level Reparables, and Overhaul

Figures 6.3 through 6.6 show the sensitivity to reliability changes of the largest cost elements from Figure 6.1. These sensitivities were derived from data and JSF OSS cost model outputs provided by NAVAIR.

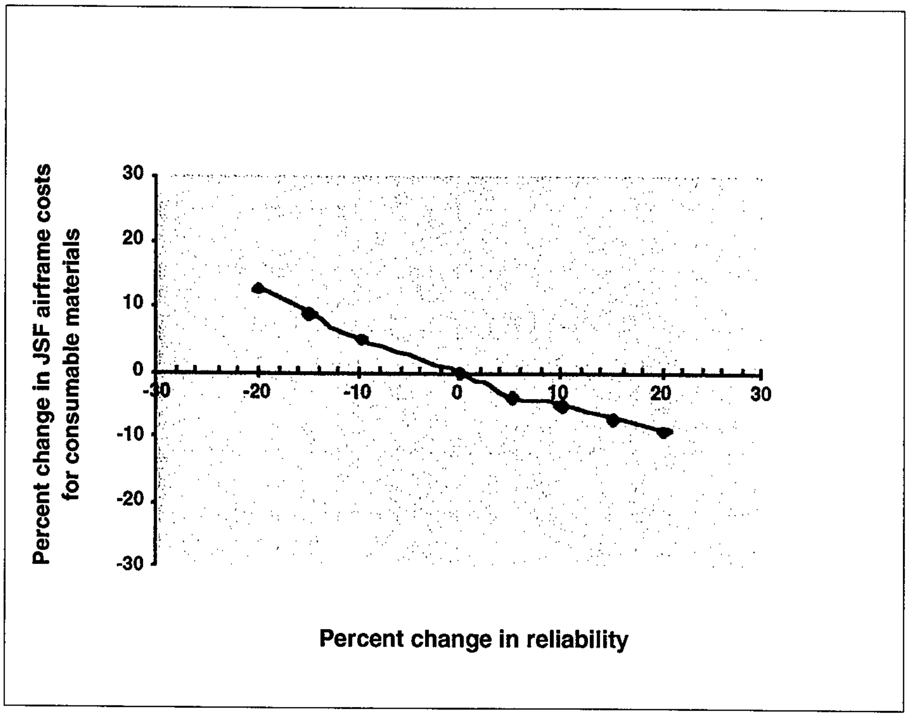

Figure 6.3—Sensitivity of Airframe Consumables to Reliability Changes

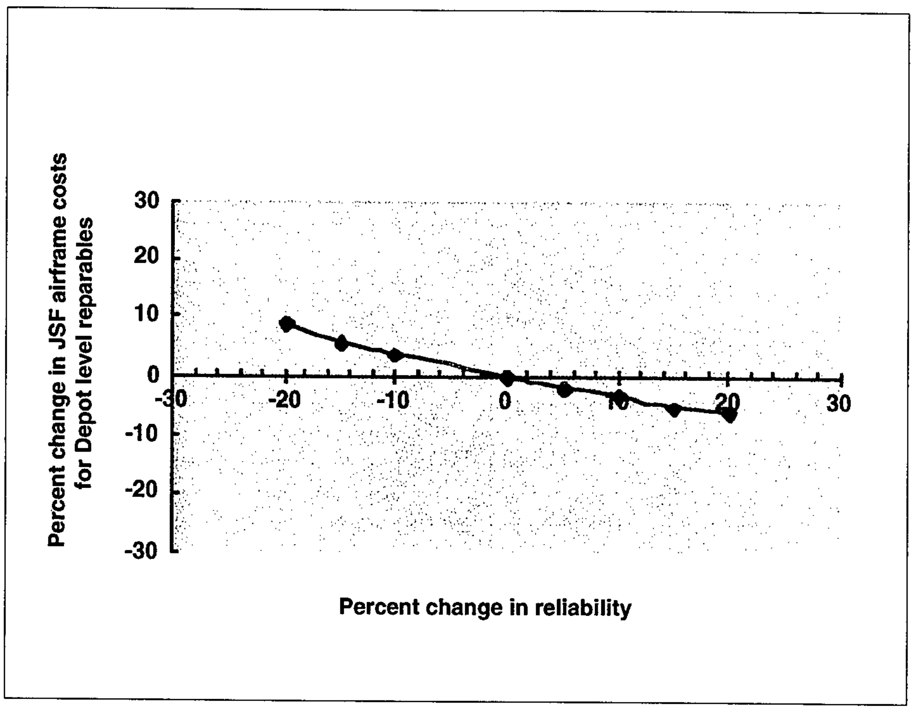

Figure 6.4—Sensitivity of Airframe Depot-Level Reparables to Reliability Changes

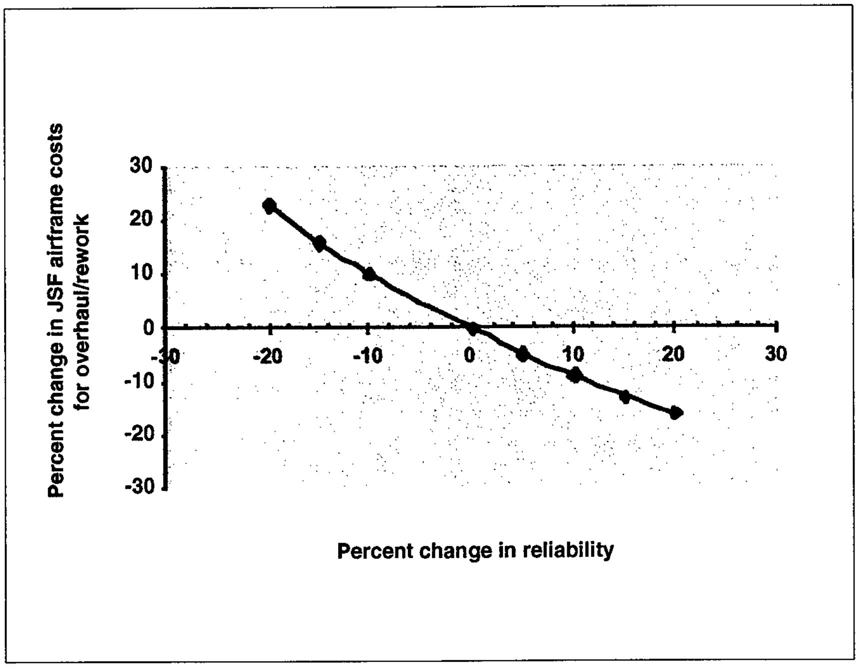

Figure 6.5—Sensitivity of Airframe Overhaul/Rework to Reliability Changes

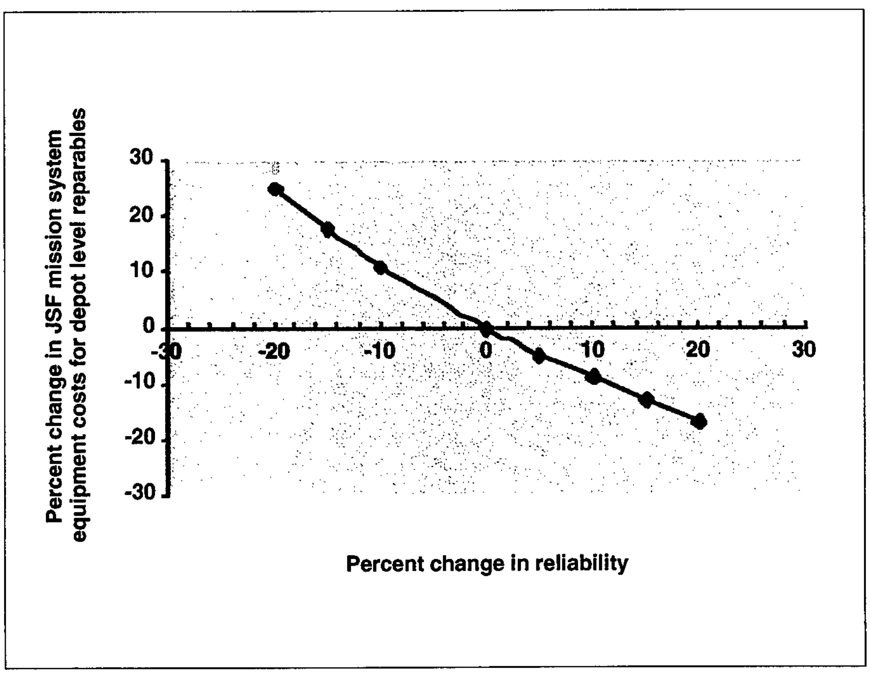

Figure 6.6—Sensitivity of Mission System Depot-Level Reparables to Reliability Changes

RESULTS

Using the values from Figures 6.3–6.6, we determined the O&S dollar savings over the operational life of the JSF fleet, assuming a 30-year aircraft life. We then calculated the amount that the production cost RCRs for the total airframe and the complete mission system package would be reduced if the reliability driven O&S costs savings were realized. The results are shown in Figure 6.7. The values in this table, like all savings values shown previously, are undiscounted to enable comparison with the historical evidence. Because the O&S savings would be achieved several years further in the future than savings in production cost, it is worth noting that corresponding discounted values are about 40 percent of the values shown in Figure 6.7; e.g., the -5.6 percent value for mission equipment with a 20 per cent reliability improvement becomes -2.2 percent when discounted.

Reliability Improvement (Percent)	Delta from Break-Even Baseline (Percent)	
	Airframe	Mission Equipment
5	-1.7	-1.6
10	-2.6	-2.9
15	-3.9	-4.3
20	-4.9	-5.6

Figure 6.7—Reliability Improvements Yield Minor Improvements in breakeven Percents

7. OTHER ATTRIBUTES OF COMPETITION

In the previous two chapters we examined the likelihood that the government would breakeven financially from the introduction of competition to the production phase of the JSF. There are several other widely-acknowledged plausible effects of introducing competition—effects that are hard to analyze in strict financial terms but that might be sufficiently important to justify their inclusion in an overall decision. Here we briefly examine five such effects.

WOULD COMPETITION AFFECT LIKELY LEVELS OF PROGRAM COST GROWTH?

We analyzed the record of procurement cost growth and development cost growth for several competitive and non-competitive weapon system acquisition programs. However, there are logical arguments as to whether greater or lesser development cost growth indicates a more desirable outcome. Program success can be judged not only in terms of cost growth, but another indicator is procurement quantity changes. Unsuccessful programs will not be likely to have increases in quantity and may very likely have decreases. Successful programs will be the opposite, not likely to have decreases and more likely to have increases.

Historical Program Data

To assess the influence of competition on program cost growth and quantity changes, we drew on a RAND internal database of Major Defense Acquisition Program (MDAP) cost histories. For both development cost and production cost we selected the estimate prepared at Milestone II (start of EMD) as the baseline and compared that with the actual costs incurred. When determining actual costs we examined only those programs that had at least some production experience (had passed Milestone III), and were at least five years beyond the milestone date.[26] We only included programs for which the most recent method of adjusting for quantity changes had been completed. We looked at programs that involved competition from the start of procurement as well as programs for which competition was initiated after some amount of original prime contractor production. In total we examined 58 programs, of which 14 involved competition and 44 did not. SINCGARS was the only electronics program involving competition,

[26] In some instances the two milestones are coincident. Some ship programs begin with contracts for the lead ship (which is taken as EMD start) plus one or more follow ships (which is taken as the start of procurement). In other cases, there may have been no identifiable Milestone II cost estimate, so the cost track begins with Milestone III.

and was unique in that the second contractor's design was completely different from the initial design. It is an example of "form-fit-function."

Table 7.1 summarizes the competitive programs. Table 7.2 summarizes the programs having no competition. The first column in these tables identifies the type of system and the program. Columns two and three present the baseline cost estimates, escalated to constant FY2001 dollars. Columns four and five present the baseline and latest procurement quantities. The final two columns are the development and procurement cost growth factors (CGF). The CGFs referenced to a Milestone III baseline cost estimate are indicated in bold to distinguish them from the Milestone II CGFs. The procurement cost growth factors are adjusted for quantity changes.[27]

Table 7.1

Cost Growth Data for Competitive Programs

	Baseline (FY 2001) Costs		Quantities		Cost Growth Factors	
Program	Development	Procurement	Baseline	Latest	Development	Procurement
Electronics						
SINCGARS-V	**233.4**	**5899.3**	**292853**	**270384**	**1.35**	**0.70**
Missiles						
AGM-65D	298.2	2666.2	32520	24914	1.04	1.49
AIM-54C	182.1	389.8	465	2483	1.67	2.42
AMRAAM	1669.8	9166.9	24335	10917	1.46	1.36
Dragon	294.5	1720.2	246575	67561	1.88	2.29
Hellfire	616.5	821.1	24600	45659	1.33	1.77
Stinger - FIM 92A/92B	284.1	1268.2	22980	38389	2.29	1.57
Tomahawk (B/R/UGM-109)	1940.0	2539.3	1082	4301	1.72	1.39
Ships						
CG 47	126.9	20368.8	16	27	1.23	0.96
DDG 51	1584.4	19714.1	18	57	2.23	1.16
FFG 7	49.5	9290.4	50	51	1.40	1.62
LHD 1	73.9	7457.1	5	7	0.93	0.99
LSD 41 (Basic)	**93.4**	**5451.3**	**12**	**8**	**1.08**	**0.88**
TAO 187	**23.9**	**3809.9**	**17**	**16**	**0.97**	**1.06**

[27] This is accomplished by adjusting the latest cost estimate from its corresponding quantity to the original quantity at the baseline estimate. The cost improvement slope for the latest estimate is used.

Table 7.2

Cost Growth Data for Non-competitive Programs

Program	Original Costs-FY01$M		Quantity		MS2 CGFs	
	Development	Procurement	Original	Latest	Development	Procurement
Electronics						
AFATDS	480.9	564.1	3184	6391	1.48	0.46
AN/TTC-39	414.0	1582.0	292	100	1.54	0.96
CSSCS	136.0	153.6	1031	3081	1.45	0.48
JSTARS-CGS	348.5	663.3	95	121	2.25	0.95
Longbow Apache-FCR	916.0	596.0	227	320	0.98	1.80
MCS	**404.0**	**1017.5**	**6365**	**8088**	**1.48**	**0.85**
SMART-T	238.3	682.4	364	320	1.32	0.71
Aircraft						
A-6E/F	**276.6**	**6571.5**	**173**	**205**	**3.93**	**0.96**
B-1B	**4375.2**	**30771.1**	**100**	**100**	**1.31**	**0.98**
C-17	4962.6	28583.5	210	134	1.57	1.70
EF-111A	296.1	1038.1	40	40	2.10	1.62
F/A-18	4183.0	19435.9	800	1015	1.36	1.54
F-14A	3883.9	19858.1	463	583	1.53	1.25
F-15	7078.6	18431.3	729	1074	1.48	1.47
F-16	1683.4	11270.6	650	2201	2.51	1.29
JSTARS	1865.5	1576.8	10	14	2.20	2.04
T-45 Training System	742.7	4182.1	300	234	1.53	1.74
Helicopters						
AH-64	2266.3	4803.9	536	811	1.20	1.75
CH-47D (Chinook)	221.4	2392.9	361	474	1.13	1.36
Longbow Apache-AFM	396.9	1178.4	227	530	1.93	2.19
OH-58D (AHIP)	347.7	2330.0	578	382	1.13	1.85
UH-60A/UTTAS	1396.2	6381.0	1107	1327	1.16	1.36
Missiles						
ACM	**2117.9**	**5782.9**	**1461**	**460**	**1.08**	**1.41**
ALCM	1749.2	5734.6	3424	1763	1.38	1.03
ATACMS-Block I	884.8	631.2	1000	2299	0.97	1.35
Copperhead/CLGP	318.0	2189.9	132650	24545	1.23	2.11
Improved Hawk	**412.3**	**2172.4**	**6554**	**5631**	**1.52**	**1.56**
Javelin (AAWS-M)	676.0	3422.1	70550	26956	1.34	1.90
Longbow Hellfire	360.3	1569.1	10896	12905	1.25	1.13
MMIII GRP	480.7	1163.5	652	652	1.22	1.46
Pershing II	1212.8	1269.5	394	278	0.99	2.14
Roland	466.1	2011.3	5778	595	1.52	2.91
SADARM-155mm	314.9	1071.8	64123	50000	1.53	1.95
TOW II	**161.7**	**3226.7**	**141224**	**142429**	**2.85**	**1.15**

Table 7.2 (continued)

Cost Growth Data for Non-competitive Programs

Ships						
MCM 1	**34.5**	**2315.1**	**14**	**14**	**1.00**	**1.03**
MHC 51	**19.9**	**1642.9**	**12**	**12**	**1.08**	**1.15**
Trident II (SUB)	**78.3**	**15192.6**	**7**	**10**	**1.32**	**0.87**
Vehicles						
Bradley/IFV/MICV	546.3	6124.1	9261	6778	2.55	2.29
DIVAD/Sgt York	372.5	4646.2	618	64	1.30	2.21
FAADS LOS-R (Avenger)	**15.1**	**1400.2**	**1207**	**773**	**3.26**	**1.13**
FMTV	74.1	8160.3	118935	86916	1.68	2.39
M-1 (Abrams)	1571.6	7474.2	3312	7822	1.83	1.59
M-1A2 (Abrams)	**683.2**	**4402.8**	**1060**	**1155**	**1.37**	**1.38**
MLRS/GSRS	**595.2**	**4325.4**	**362832**	**489114**	**1.53**	**0.92**

The significance of the baseline relates to the quality of the estimate available at the baseline and its implication for cost growth. At MSIII, generally much more and better information is available than at MSII. Consequently, one would expect lower growth as measured from MSIII compared to MSII.

Procurement Cost Growth

The simple averages of the procurement cost growth factors (CGF) for the groups of systems in Tables 7.1 and 7.2 are shown in Table 7.3. One would expect that competitive programs might have lower cost growth than non-competitive programs. The differences observed in Table 7.3 are not all consistent with this hypothesis. Furthermore, because of the small sample sizes, none of the differences is statistically significant at the 10 percent level. This is demonstrated by the ships and missiles CGFs considered both separately and together. Both the ships and missiles show higher average cost growth for competitive programs than for non-competitive programs when considered individually. When combined, the average competitive CGF is less than the non-competitive value. A scatter diagram of the procurement CGFs is shown in Figure 7.1. The only clear difference exhibited by these data is that electronics programs have significantly lower cost and cost growth than non-electronics programs.

Table 7.3

Simple Averages of Procurement Cost Growth Factors.

System	*Competitive*	*Non-Competitive*
Electronics	0.70	0.89
Ships	1.11	1.02
Missiles	1.76	1.68
Aircraft		1.46
Helicopters		1.70
Vehicles		1.70
Aircraft, Helicopters & Vehicles		1.59
Ships & Missiles	1.46	1.54
All Non-electronic Systems	1.46	1.57

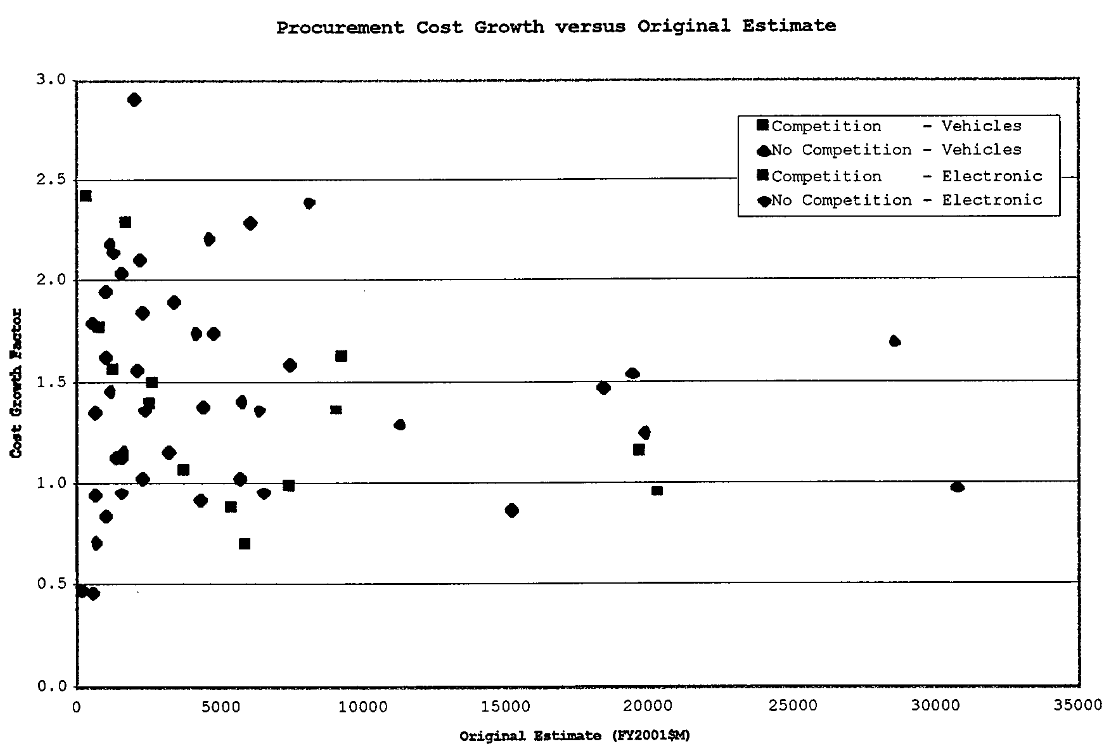

Figure 7.1—Scatter Plot of Procurement Cost Growth Factors

Our data contain no competitive aircraft, helicopter or vehicle programs. However, note that for non-competitive programs, the combined average procurement CGF for these systems is very close to the average for ships and missiles, 1.59 versus 1.54 respectively—a very small difference.

Development Cost Growth

While procurement cost growth was of primary importance to this project, we also considered development cost growth. A scatter plot of the development CGFs is shown in Figure 7.2 and the simple averages are presented in Table 7.4.

Table 7.4

Simple Averages of Development Cost Growth Factors

System	Competitive	Non-Competitive
Electronics	1.35	1.50
Ships	1.31	1.15
Missiles	1.63	1.41
Aircraft		1.95
Helicopters		1.31
Vehicles		1.93
Aircraft, Helicopters & Vehicles		1.80
Ships & Missiles	1.48	1.35
All Non-electronic Systems	1.48	1.62

Interpreting the differences between competitive and non-competitive programs in terms of development CGFs is not as clear as for procurement CGFs. The data used to obtain the factors in this study are the total development cost for the program through all model changes of the weapon system. Also, most, if not all, of the programs included here did not involve competition during the development phase. Consequently, if competitive programs are more successful than non-competitive programs, we might expect development costs to grow, reflecting continued development of new models of the weapon system. This is countered by the hypothesis that successful programs will not have difficulties during development leading to increased development costs. As with the procurement CGFs, the results are mixed and the differences between the competitive and non-competitive development CGFs are not statistically significant at the 10 percent level.

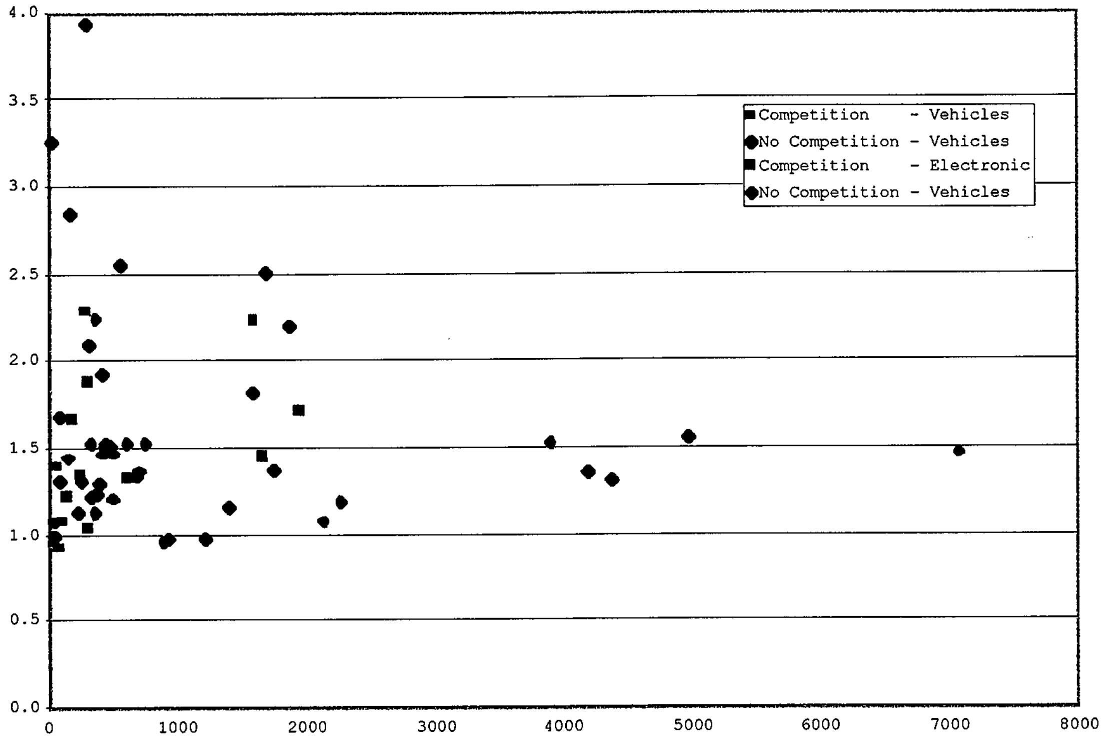

Figure 7.2—Scatter Plot of Development Cost Growth Factors

WOULD COMPETITION IN THE JSF PROGRAM STRENGTHEN THE INDUSTRY BASE?

The defense industry has been undergoing consolidation, and general reduction in capacity, for more than two decades. Today only three U.S. firms are capable of functioning as a prime in a major aircraft weapon development and production program, down from nine in 1980, and the number of first- and second-tier suppliers has likewise dwindled. The JSF is expected to be the only new major fighter aircraft development program in the next couple of decades. If all that business is granted to one firm, or even to a team consisting of two of the present three prime-level firms, there is concern that the loser(s) would be unable to sustain a competitive posture in the future, thus seriously reducing the breadth and depth of the U.S. fighter aircraft industrial base.

This issue was not addressed in depth in the present study. However, it has been examined in several other studies by RAND and other firms, although only a few of those

resulted in formally published results.[28] Results of those studies are mixed and generally not conclusive. There is broad agreement that vigorous competition by experienced firms contributes to the quality of the product, but exactly what constitutes a bare minimum in breadth of competition, or whether the United States is nearing a critical point in the diminishing stock of combat aircraft developers, is unclear. A brief survey of available information, published and unpublished, shows that no one has persuasively argued that a winner-take-all strategy in the JSF would inexorably lead to the loser exiting the fighter aircraft business, or even that the loser would clearly loose an important degree of capability to continue as a competitive supplier of combat aircraft systems in the future.

It should also be noted that competition in *production* would have only second-order contributions to the industry base for *developing* future fighter aircraft. A production contract does provide for sustaining engineering and enables expenditure of independent research and development (IR&D) funds for some technology development, but it does not directly support the kind of staff or facilities needed for creative design of new systems. This issue is discussed more fully in Drezner, et al. (1992).

We conclude that support of the industry base at the prime-contractor level would provide an important, but not compelling, reason for sustaining competition during production of the JSF.

Subsystems

At the subsystem level the issue is somewhat different, especially in the case of certain kinds of electronic subsystems. There are some cases where the industry is already down to a single supplier, and there are strong arguments in favor of encouraging another firm to enter those specialized areas. However, the need is for additional teams developing new technology and related system architectures, and again this sort of work would not necessarily be supported by competitive production of the JSF. Indeed, the needed strengthening of the industrial base in these specialized areas would be better achieved in the near term by specifically supporting competitive development of subsystems that might be introduced into other combat systems and future versions of the JSF. This matter is discussed more fully in Chapter 9.

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[28] Lorell, Mark A. and Hugh P. Levaux, *The Cutting Edge; A Half Century of U.S. Fighter Aircraft R&D*, Santa Monica, Calif.: RAND, MR-939-AF, 1998; Lorell, Mark A., *Bomber R&D Since 1945; The Role of Experience*. Santa Monica, Calif.: RAND, MR-670-AF, 1995; and Drezner, J., et al., *Maintaining Future Military Aircraft Design Capability*, Santa Monica, Calif.: RAND, R-4199-AF, 1992.

WOULD COMPETITION REDUCE PROGRAM RISK?

Development of a new weapon system inevitably involves uncertainties and risks. The multi-phase approach to such development, with explicit attention given to concept refinement and risk reduction before full-scale engineering development begins, helps to ameliorate risks but cannot eliminate them. Thus any additional action or policy that could further control risks deserves consideration.

It is widely agreed that simply increasing the number of firms conducting parallel and independent development of a new system inherently reduces the overall risk of failure. If one firm has a 0.99 probability of success, then two equally qualified firms working independently on the same project should result in an overall probability of project success of 0.9999 (assuming that the failure sources are random, etc.). But that kind of benefit from multiple sources affects a project mostly in the development phase; competition during production appears to make little contribution toward overall project risk reduction.

WOULD COMPETITION FOSTER INNOVATION AND PRODUCT QUALITY?

As in the case of project risk, the most effective way to foster innovation and improve product quality would be to introduce a second source during product development. A second source in production also might have an important effect on product quality (through rigorous attention to quality control) and thus affect operational reliability of the product. Unfortunately, studies that explicitly examine the effects of second sourcing on product quality are hard to find. One might reasonably expect some such effect, but the extent, even the direction, of the effect is problematic. On one hand it can be argued that:

- The second source would be starting the production learning process all over again and would suffer from quality problems that the original source had already solved.
- The increased emphasis on low production cost might create new quality problems in both suppliers.
- On the other hand:
- The second source could benefit from most of the first source's experience and thus start out producing items of superior quality.
- Enhanced competitive pressure would lead both suppliers to improve quality.

Measuring product quality can be contentious, because no single quantitative index of product quality is widely accepted. It would be desirable to examine several measures of quality for a variety of past programs to see if any of them could be correlated with the introduction of a second manufacturing source.

In the time available for this study, however, we were only able to draw on earlier RAND research.[29] We could find no other relevant research. That research collected consistent and reliable data across several missile systems for only one index: flight test results. That limitation is not as restrictive as it might seem. Flight test reliability information may be the best single parameter that can be used, because it provides a good indication of whether a missile will hit a target.

Tomahawk Experience

Here, we summarize the second sourcing of Tomahawk production experience and the implications on flight test reliability. It is the most complex flight vehicle that was second-sourced for which data are available.[30] The primary reason for second-sourcing the Tomahawk was not to reduce cost but to improve system reliability. The Program Office was seriously concerned with Tomahawk reliability during system development and was not satisfied with the prime contractor's, General Dynamics Convair (GD/C) Division, effort to deal with the problem. Since nothing gets management's attention as effectively as the prospect of having to share production with a competitor, the Program Office began thinking about second sourcing early in the program.

It is difficult, however, to establish a cause-and-effect relationship between second-sourcing and improved quality. Quality improves over time in all programs as more tests are conducted and problems isolated, and that was true in the Tomahawk program. The question is whether a link between second sourcing and quality improvement can be shown.

We know that (1) uncorrected quality assurance problems existed on and off between 1978 and 1982, (2) dual-source procurement was authorized in 1982, (3) system reliability as measured by flight-test results improved in the period 1983–86. We also know that Program Office did not rely exclusively on second sourcing to influence GD/C to focus on the quality

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[29] Birkler, J.L., et al., *Issues Associated with Second-Source Procurement Decisions*, Santa Monica, Calif.: RAND, R-3996-RC, December 1990.

[30] Given their greater complexity and longer flight times relative to other missiles, cruise missiles offer the best available analog. The Advanced Cruise Missile, ACM, was also second sourced, but the details of that procurement remain classified.

assurance problem. The Defense Contract Administration Services Plant Representative Office (DCASPRO) issued five Method C corrective action requests between November 1981 and May 1982 to deal with what the Program Office perceived as serious quality assurance problems. In June 1982 DCASPRO issued a Method D corrective action request, an action that is taken only "after sequentially exhausting every other avenue available by the Government to obtain corrective action by the manufacturer." Reliability showed a perceptible improvement by mid-1983, and overall missile reliability eventually achieved a level comparable to that of other missile programs.

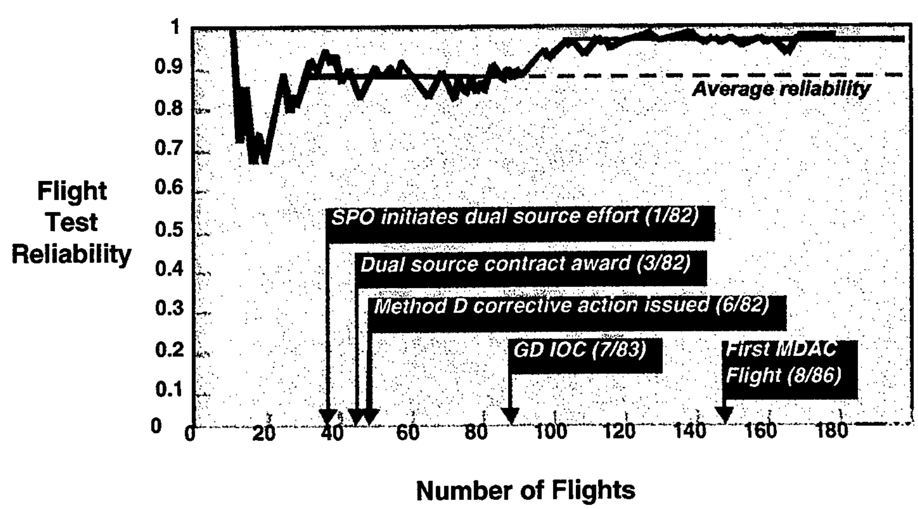

Figure 7.3—Tomahawk Missile Reliability Improved Some 10 Percent with Competition

Figure 7.3 displays Tomahawk (GD/C) long-term flight test reliability.[31] At that time Tomahawk had almost 180 flights and achieved a reliability level of about 97 percent, but it is different from the other missile systems examined in that flight-test reliability was not

[31] The model used for the estimation and forecasting of reliability was the Lloyd-Lipow model which calculates overall system reliability as a function of the number of failures and the number of tests. Failures are weighted to accommodate the small sample sizes and the presumed capability to improve the design in the remainder of the development phase, thus not repeating a failure mode.

maintained at the 90 percent level until the 75th flight. The other missiles attained that level much earlier in their flight test histories—TV Maverick at test 6 and IIR Maverick at test 18.

When the history of Tomahawk flights 27 through 78 is compared with that of flights 80 through 177, the former set is found to have an average reliability of 87 percent and the latter, about 96 percent. This difference is statistically significant at the 95 percent confidence level, and there is some reason to believe that GD/C's effort to improve reliability began to show results at about the time of flight test 75 in March 1983. Events before that date that could have affected GD/C's attitude toward quality assurance were:

- Jan 1981: CMP initiates dual-source effort
- Nov 1981–May 1982: Five Method C corrective action requests issued
- Mar 1982: Dual source contract awarded
- Jun 1982: Method D corrective action issued

According to the Program Office and contractor personnel, both second sourcing and the corrective action requests were important. The proximate cause for action, however, appears to have been the DCASPRO letter of June 24, 1982, implying drastic action if "the Government's missile program is not measurably improved" in the next 120 days. During that grace period, GD/C formed a corporate team to identify and correct quality assurance problems, and three of the five Tomahawk flights between November 1982 and March 1983 were successful (one of the two failures was apparently related to the MDAC land-attack guidance system). Reliability improved steadily thereafter. The problem all along, according to the Program Office, was GD/C's disinclination to take the strenuous action required to correct engineering and manufacturing quality control problems. Imminent competition and the more direct corrective action requests both contributed to a change in corporate attitude. It would be mere speculation, however, to claim that one was more important than the other.

Does second-sourcing result in a more reliable product? According to the Tomahawk Program Office, improved quality assurance, not cost reduction, was the primary reason for second sourcing in the Tomahawk AUR program. There is little doubt that competition forces an attitudinal change on contractors who may have grown complacent in single-source production. When reliability is an important source-selection criterion, it has to be taken seriously. But since our evidence comes from a single program, we cannot say definitely that equipment produced in second-source programs has a superior reliability record.

WOULD COMPETITION AFFECT THE LEVEL OF INTERNATIONAL PARTICIPATION?

Maintaining competition during the production phase could clearly affect foreign industrial participation on the JSF program. Traditionally, acquisition programs with significant foreign participation included carefully negotiated formal government-to-government agreements specifying the participation of specific foreign firms and allocating work share and work tasks. In past international collaborative programs, the value of the work allocated to foreign industry usually closely approximated the financial contribution of the participating governments. Changes in any of the industrial aspects of a program typically would require a major renegotiation of the government-to-government agreement. Thus, in a traditional international collaboration program, introducing competition in the production phase could raise serious issues regarding possible changes in work share, work allocation, and work tasks, as agreed in the original government-to-government MoUs.

JSF however is a trail-blazing program which has broken out of the traditional mold of collaborative programs. For the EMD phase, JSF planners have agreed that there will be no guaranteed foreign work share based on government-to-government agreements. No detailed discussion of specific industry participation, work share, or work tasks will be included in government-to-government agreements. All foreign participants recognize that there are no guarantees that work share will be proportional to the participating government's contribution to EMD.

Foreign industry participation is and will be determined and managed entirely on the industry level. Foreign industry participation is available through the prime contractors, subcontractors, and vendors. Foreign companies that wish to participate in the program compete with U.S. companies as well as companies from third countries for work share and work tasks. Companies are selected on the industry level on a best value basis, whether they are foreign or domestic. This approach is strongly incentivized by the on-going competition between the two prime contractors and the intense pressure to meet very demanding URF cost goals established by the Program Office from the earliest phases of the program.

On the other hand, foreign participating governments have a recognized expectation of receiving an equitable return on their investment through industry participation in the program. Both of the competing prime contractors recognize the importance of including significant industrial participation on their teams representing the countries that are participants in the CDP and that are likely to play a major role in EMD and production (see Tables 7.5 and 7.6). Both prime contractors recognize that they would be politically at a competitive disadvantage in the

down select if their team did not include equitable industrial representation from the key foreign government participants in the program. This is particularly true in the case of the United Kingdom, since the UK formally has been granted a position of influence over the final downselect.

Table 7.5

Companies Teamed with Boeing During CDP[32]

Company	Role
Aerosystems	logistic support
Alcoa	castings
BAE SYSTEMS	fuel system, cockpit displays, electronic warfare
B.F. Goodrich	fuel system
Cytec Fiberite	composites
Dowty	actuators
EDO	weapon bay swing arm system
FHL	attitude control
Flight Refuelling	fuel system
Fokker	wire bundles, aerostructures
GE Aircraft Engine	alternate engine
Harris	network cards
Hexcel	composites
Honeywell	subsystems
IBM/Dassault	information systems
Martin Baker	ejection seat
Moog	actuators
Parker	fuel system
Raytheon	mission systems
Rolls-Royce	vertical lift systems
TRW	navigation, communications
United Technologies	F119 engine, subsystems

[32] Merrill Lynch & Co., Global Securities Research & Economics Group, Global Fundamental Equity Research Department, "The Pilot—No. 13: The Joint Strike Fighter Program," in *A Monthly Global Overview of the Aerospace & Defense Sector*, 6 October 2000, p. 23. Note that, while the suppliers and products shown are believed to be accurate as of October 2000, these arrangements are subject to change as the program evolves. The lists are therefore intended to be representative, not definitive.

Table 7.6

Companies Teamed with Lockheed Martin During CDP[33]

Company	Role
BAE SYSTEMS	aft fuselage, flight controls, vehicle management computer, electronic warfare
B.F. Goodrich	landing gear
Cytec Fiberite	composites
EDO	weapons stores
Fokker	power panel, wiring
General Electric	alternate engine
Harris	electronics
Hexcel	composites
Honeywell	power management
Kaiser Electronics	displays
Litton	electronics warfare
Martin Baker	ejection seat
Moog	actuators
Northrop Grumman	center fuselage, electro-optical sensors, radar
Rolls-Royce	lift fan, ducts, alternate engine (F120 with GE)
TRW	communications, navigation, actuation control
United Technologies	F119 engine, subsystems

Not surprisingly, both the Boeing and the Lockheed Martin teams include significant representation from British firms. Interestingly, the proportional value of the program that will go to British firms is likely going to be higher than the proportional value of the British government contribution. In other words, British industry is actually likely to get a better deal than it would have had in a traditional collaboration program, where industrial participation is exactly proportional to the foreign government contribution. For example, on the Lockheed team BAE Systems is treated as a "Partner" along with Northrop Grumman, while on the Boeing side many British firms are part of the Boeing "One Team" unified management structure.

On the other hand, the specific British companies involved and the work tasks they undertake vary significantly between the two prime contractor teams. This is of course the result of the prime contractors and other suppliers having been granted the authority of determining foreign industry participation on their own, based on their own criteria and best business practices. Foreign firms were selected based on best value standards, based on each team's

[33] Ibid.

technical and best value needs. Thus, the specific companies and specific work tasks vary between the two teams, but the overall foreign representation by country is roughly the same. There is thus also equitable participation on both teams by firms from all the other countries that are participating in the CDP. This participation is likely to continue during EMD and into production.

Thus, the revolutionary way that the JSF international program is incentivized makes it highly unlikely that recompetitions during the production phase will dramatically affect overall industrial participation by foreign companies. This is because in any new competition, the primes will again recognize that equitable representation of foreign participants' firms on their teams will be a factor in deciding which team wins the competition. Neither team will want to risk losing the competition by being perceived as ignoring equitable representation of key foreign participating governments' firms. On the other hand, the enormous competitive pressures to meet demanding URF cost goals will ensure that the primes and their suppliers will select foreign firms based on best value principles and technical needs, and not merely politics.

In conclusion, we believe that competition during the production phase could lead to a change in specific foreign firms and specific foreign work tasks. On the other hand, we are convinced that competition of any type will still preserve an equitable industrial share in the program for the major participating foreign governments. Indeed, it appears that the incentives in the program could even lead to over representation of foreign firms, compared to the traditional approach of officially mandating that industrial participation remain precisely proportional to foreign government contribution to the program. Therefore, we conclude that competition during the production phase poses no serious problems for international participation.

8. NEAR-TERM POLICY OPTIONS FOR COMPLETING THE JSF

We have examined, with varying degrees of rigor and completeness, the major program features that might be affected by introducing competition in the production phase of the JSF. We now must assemble those disparate pieces of information and draw an overall conclusion on how such competition might be introduced, and on the balance of advantages and disadvantages resulting from such competition.

COMPETITIVE PRODUCTION OF THE JSF

The immediate and direct policy question is whether to take action during development of the JSF that will establish a competitive production source for part, or all, of the JSF weapon system. We assume such competitive production would start with the LRIP units and extend throughout the JSF production program.

We have analyzed the expected effects of such competition on production costs, O&S cost, future cost growth, and several other possible consequences of competition, and we have examined those issues for competition in production of the airframe and the mission equipment. In some areas the results appear conclusive, in other areas less so. Those individual results and interpretations must be integrated into an overall assessment.

Any such integration must be subjective, with the answer depending on the relative weighting one gives to the various consequences of competition. A useful method for conducting a subjective integration is the "stoplight" chart. Each element is assigned one of four colors:

- Green: The assessment is unequivocally positive;
- Yellow: The assessment is mixed or uncertain; neither a strong positive nor negative argument can be made on the basis of available data;
- Red: The assessment is unequivocally negative.
- Grey: Available data and analysis methods are inadequate and we cannot make any analytically valid assessment.

The results of our analyses are summarized in Fig. 8.1 using this display strategy. Explanation of our interpretations are described below.

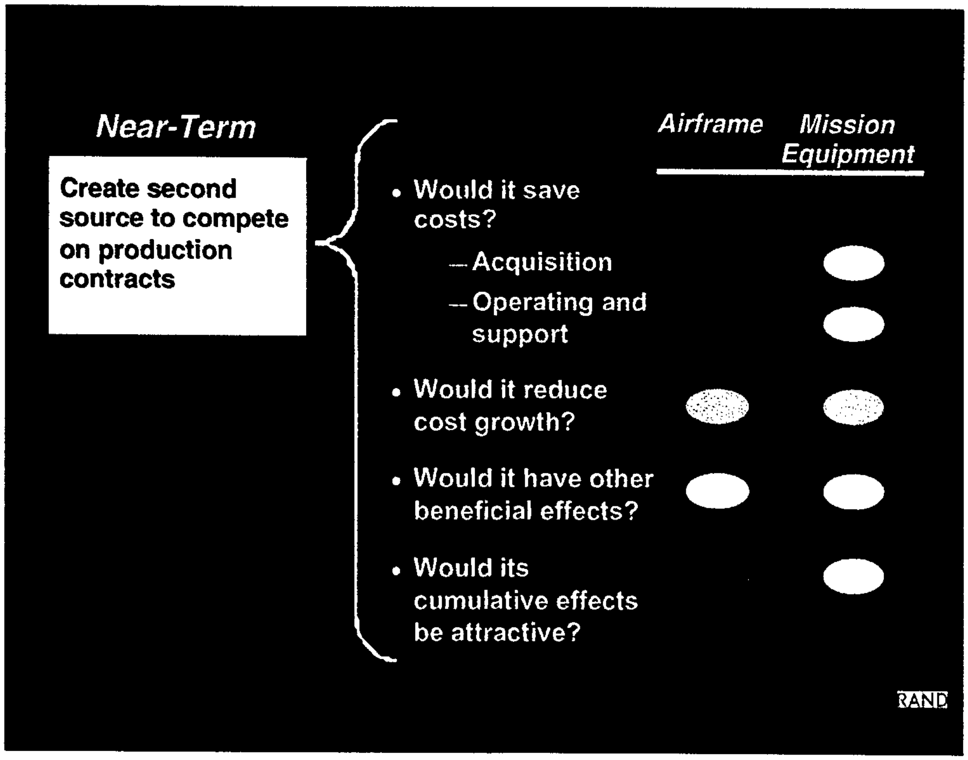

Figure 8.1—Would the Introduction of a Competitive Second Source Be Reasonable?

WOULD IT SAVE ACQUISITION COST?

Airframe: RED. We believe there is only about one chance in five of recovering the investment necessary to establish a competitive producer for airframe and major subsystems.

Mission Equipment: YELLOW. Our analysis shows there is better than an even chance of recovering the investment needed to establish a second supplier of mission equipment if the second source builds-to-print following the design of the winning prime. However, achievement of significant savings is far from assured. If the second source was directed to design its own components to a form-fit-function specification, the chance of recovering investment slips to only slightly better than even and that strategy would complicate logistic support of the system. However, those estimates were made on the assumption that the design would be reasonably stable over the full 3,000 unit production run. If the mission equipment will be upgraded periodically, then the cost of introducing competition would have to be recovered over smaller production runs, thus increasing the RCR needed to breakeven. Because of the inherent

uncertainty regarding such future actions, no strong argument can be made for or against competition on the basis of OGS cost savings.

WOULD IT SAVE OPERATING AND SUPPORT COSTS?

Airframe: RED. Competition might lead to improvements in system reliability, thus reducing O&S cost, but not nearly enough to project a good chance of recovering investment.

Mission Equipment: YELLOW. Reliability improvements have a stronger effect on reducing O&S costs, but not enough to recover investment. Combining such potential O&S savings with the analysis of production cost improves the overall chance of recovering investment, but still leaves considerable uncertainty. Again, no strong argument can be made for or against competition on the basis of O&S cost savings.

WOULD IT REDUCE COST GROWTH?

Airframe and Mission Equipment: GREY. The historical data are so sparse and mixed that no reliable conclusion can be drawn.

WOULD IT HAVE OTHER BENEFICIAL EFFECTS?

Airframe and Mission Equipment: YELLOW. Competition would probably yield some beneficial effects through strengthening the industry base and moderating overall program risk, and there is anecdotal evidence of improvements in innovation and product quality. However, the quantitative historical evidence for those benefits is weak or non-existent. We judge the overall result as tending toward positive but still basically inclusive.

WOULD ITS CUMULATIVE EFFECTS BE ATTRACTIVE

Airframe: RED. There is strong probability that competition would not lead to savings large enough to pay back the front-end investment. Those potential net costs are not outweighed by the other potential benefits of competition where the expected consequences are uncertain or neutral.

Mission Equipment: YELLOW. This assessment is less definitive than for the airframe. Might the combination of several "neutral" elements lead to a positive judgement? We believe not, for the reasons spelled out below.

If the competition were build-to-print, the chance of overall cost savings through reduction in production cost and O&S cost would be better than even, maybe even approaching two chances out of three, but still not a strong expectation of significant net cost reductions. Further, any benefits to industrial base, risk reduction, and innovation likely would be relatively small because the second source would simply be replicating the winning team's design. No strong expectation of overall benefits.

If the competitor developed its own design to a form-fit-function specification, we believe the only practical approach would be to develop an entire mission equipment set rather than one or more individual elements, such as a radar (the rationale for this judgement is discussed in the following chapter). Such a development's additional cost means that it would have only slightly better than an even chance of breaking even. The potential benefits to the industrial base, risk reduction and innovation are stronger than for the BTP option but still not enough to build a conclusive argument supporting the additional investment of several billion dollars.

NEAR-TERM EFFECTS ON INTERNATIONAL PARTICIPANTS

Throughout this analysis it was recognized that both industry teams competing for the JSF have participants and suppliers from other nations, mainly the UK. Any recommendation to introduce competition in any part of the JSF production program could affect existing agreements with some of those international firms, and some consideration was given to the possible consequences of such affects. However, our conclusion against such competition makes this matter moot.

ARE THERE LIKELY, NEAR-TERM COMPETITORS TO THE JSF PROGRAM

As discussed in Chapter 7, the JSF as now envisioned is dominantly superior in both cost and performance, compared with any other fighter and attack aircraft now in production or likely to be in production within the next decade. Unless the JSF program encounters serious problems in cost or mission capability, we see no serious competitors in the next decade or so.

OVERALL CONCLUSIONS

Our overall net conclusion is that there is no persuasive basis at this time for investing in a second source for production of all, or any part, of the JSF weapon system. This conclusion does not apply to the engine, which was not included in our analysis.

9. WHAT COMPETITION OPTIONS EXIST IN THE FAR TERM?

The production phase of the JSF is expected to extend over a period of roughly 25 years, during which some 3,000 aircraft will be delivered to the U.S. services. If history is a guide we can expect several new versions to be introduced during that time as mission needs evolve and new technologies become available. The timing and exact content of those upgrade programs cannot be defined at this time, but it seems likely that they will offer opportunities for competition in both design and production activities. Other systems might also emerge that could compete with the JSF for at least certain missions. It seems useful to look ahead and project as best we can the nature of such future competitions and to identify how they might affect the JSF program and any near-term actions needed to enhance the effectiveness of those options in the future.

BEST OPTION WITHIN THE JSF PROGRAM: COMPETE MISSION EQUIPMENT

In principle, any competition option examined in the previous section could be applied in the future. However, history suggests that aircraft vehicle configurations do not evolve radically throughout the life of a fighter aircraft design. Such airplanes typically grow in gross weight, and modest refinements are made in aerodynamic performance and in details of structure design, but the basic vehicle design remains relatively static. Furthermore, the analysis of the vehicle structure and major subsystems described in the previous section showed little promise of breaking even financially through introduction of a second production source, and there is no apparent reason to expect that to change in the foreseeable future. We therefore see little opportunity to introduce competition in the future for production of vehicle structure and major subsystems.

The mission equipment presents more attractive opportunities for future competition. The most important reason for this expectation is that mission system components are likely to undergo relatively rapid evolution in both mission needs and enabling technologies. By the time the JSF enters operational service roughly ten years from now there is a strong probability that the operational concept will have changed somewhat, placing a different distribution of emphasis on the various elements of the electronics suite of sensors, displays, and associated computation methods. Furthermore, the relevant technologies are advancing rapidly, thus enabling improvements in capabilities over the suite now being developed for the initial versions of JSF. Finally, the mission system constitutes the eyes and ears of the JSF, and advances in mission system performance can have very large leverage on overall weapon system effectiveness.

For these reasons we expect that new designs for mission equipment will emerge over the next decade. Does it make sense to introduce a competitive second source for design and production of that new mission equipment suite? We believe consideration of a second source is justified because the potential improvements in JSF mission effectiveness through upgrades in mission equipment are so large as to justify the stimulus to technical innovation that is believed to be achieved through competition. The argument does not have to rely entirely on potential cost savings; some increase in cost might be justified as investment in improved mission capability through technological innovation.

To devise an overall concept for competition in design and development of future mission equipment we need to examine three issues: (1) Can individual elements of the mission equipment suite be competed or must such competition encompass an entire avionics suite; (2) should the second source compete on the basis of BTP or FFF; and (3) what should be done in the near term to enable future competition? We will examine each in turn, drawing on features of the mission equipment designs being offered in the present JSF competition.

INTEGRATED DESIGN VERSUS SUBSYSTEM DESIGN[34]

Mission system avionics will perform a variety of functions in the JSF. They will control the plane and monitor its resources. They will provide information that pilots need to perform their missions and to control and/or guide weapons to targets. And they will provide communication links to report mission status.

In the past, contractors working on conventional aircraft programs typically have developed discrete requirements for each avionics subsystem. But with the JSF, contractors are integrating these avionics systems. Driven both by the JSF's complex mission requirements and by desires to save costs, contractors are using combinations of subsystems to accomplish tasks heretofore performed by single subsystems. Contractors have parceled out the JSF's radar functions, for example, between the integrated core processor (ICP), electronic warfare (EW) components, and other subsystems. Traditionally, radar functions would have been performed by a single stand-alone subsystem. Moreover, the EW and the communications-navigation and identification friend or foe (CNI) subsystems share antennas, an integrated core processor—which replaces most of the separate processors in each subsystem—and common support electronics.

[34] In our original analysis, we examined individual elements of the mission system in detail, but due to proprietary constraints that discussion is reported separately.

Each of the two prime contractors working on the JSF expects that such integration of mission system avionics will enable it to significantly reduce these components' cost and weight and boost their performance.

Each prime has analyzed the JSF mission operational requirements and developed an integrated mission equipment package in which traditional subsystems take on non-traditional functions. However, the two designs differ in how functions are distributed across different hardware and software elements, and how they are integrated into the flight vehicle. The differences vary from minor to major. This directly effects the ability of a subsystem vendor to enter into a future competition against the firms participating in the initial production program. Traditional methods of fostering avionics competition may not be effective given the design strategy being employed.

Reverting to a conventional federated, or stand-alone, subsystem design would facilitate future competition at a component level. However, with such a conventional design, the overall program cost would be greater than with an integrated mission system package. This does not mean some level of traditional competition for each avionics subsystem is futile. It means a detailed assessment of each subsystem is required before the decision to compete the subsystem (or a part of it) can be made. The decision is not whether another vendor could make its subsystem fit in the winning team's design. Rather, a hypothetical decision to fit a competitor's component into the existing JSF design would need to be assessed on the following factors:

- How much would it cost to make the new design fit?
- What innovations would the proposed new design bring to the existing mission system?
- What else would be needed to foster competition for the entire avionics package.

Our preliminary analysis or these issues indicates that the Defense Department should consider a new approach to fostering competition for the mission system at a future upgrade: compete the entire mission system package.

The integrated systems approach enables significant cost, size, and weight savings for the mission systems package. Competing at the mission system level would empower the competitor to be innovative and develop systems that enhance mission performance while minimizing cost. In addition it would help preserve the avionics integrator industrial base.

SHOULD COMPETITION BE IN FFF OR BTP MODE?

In Chapter 5, where we examined near-term opportunities for competition, we considered options where the second source would competitively build a component or subsystem using the original source's design (build-to-print) or design and manufacture its own version that would fit into the existing overall system (form-fit-function) as a direct substitute for the original source's design. Which approach should be followed by our suggested second source for future mission equipment?

In principle it should be possible for the prime to design a follow-on mission equipment suite and then a second source could compete for production on a minimum-cost basis. However, we argued earlier that a major future benefit from a mission equipment second source would be to encourage innovation and exploit advances in technology. The advantage being sought here is different from that of the near-term competition modes examined in Chapter 5; here we are primarily seeking design improvements, not just reductions in manufacturing cost. To achieve such benefits it would be necessary for the second source to create its own design for all or parts of the mission equipment suite.

Such a FFF strategy would require close cooperation between the overall system prime and the competitive second source for mission equipment because the second-source design would have to fit into the existing flight vehicle and overall weapon system design.

NEAR-TERM ACTIONS TO SUPPORT FUTURE COMPETITION

One strategy the DoD could employ would be to wait for a few years until changing mission needs and evolving technologies justify an upgrade in mission equipment, then evaluate the option of introducing a competitive second source. However, that might not provide the maximum benefits. Near-term stimulus might not be available to support appropriate technology innovation at the desired rate, and some key members of the industry might leave the business. Thus we want to consider sustaining a second source at a level less than full EMD but sufficient to ensure technology advance and retain a vigorous industry base to support future competition.

How might such a sustainment phase be structured? We suggest some guidelines. Following the arguments outlined above favoring an integrated design approach, it would be appropriate to organize a "shadow mission system design team" to develop a next-generation mission system. The strategic goal of that shadow team would be to create a strong competition to the JSF for design and production of the second-generation mission equipment suite. The

strength of that competition would depend on how well they used available resources to develop critical technologies, nurture the industry teams best capable of providing such technologies, and integrate the results into a next-generation design concept.

How much might such a shadow team cost? We can draw on some related research in which we examined the minimum size at which an aircraft design team must be sustained through lean times in order to be competitive on the next design competition. In that study we identified five categories comprising the overall activity needed to sustain a vigorous design capability:[35]

- Technology development.
- Engineering and management staff.
- Facilities.
- Financial support.
- Institutional structures and management organizations.

Our survey of several aircraft development firms over several cycles of lean and full business activity suggested that "...the historical minimum size that design organizations reached (was) characterized by about $100 million in annual funding and 1,000 people in engineering and technical management."

We have not conducted a similar survey of modern military avionics development firms but we have no reason to believe that a team preparing to compete for development of a future mission equipment suite for the JSF would be larger than an equivalent aircraft design team. Thus we estimate that the annual sustainment cost for such a team would be roughly $50 to $100 million, depending on the range of system elements subject to vigorous development activities.[36] This investment rate would equal some 10–20 percent of the annual cost of full-scale EMD for the mission system.

Assuming that such a shadow competitor might be sustained for five years before deciding on whether to implement a full competition for an upgraded mission system (and hence the need to invest in a full EMD for the competitor), that would yield a total investment of maybe $250 to $500 million, or roughly 10 to 20 percent of full EMD cost. But that would not

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[35] Drezner, Jeffrey, et al.; *Maintaining Future Military Aircraft Design Capability*. Santa Monica, Calif.: RAND, R-4199-AF, 1992.

necessarily represent a net outlay. It seems reasonable to assume that the suppliers of mission system equipment to the JSF program would view such a program as a threat of future competition, and they might consequently work to reduce their own prices and hence be better prepared to meet such future competition. How large would such price reductions have to be in order to cover the shadow competitor costs? Making a limit-case assumption that the price reduction would affect the entire production run of mission system equipment, the results are shown in Table 9.1. Of course, if the price reduction affected only a later segment of the production the required reductions needed to breakeven would be greater. But even if the "recouped cost" was less that the amount necessary to fully cover the investment in the shadow competitor, the benefits of having full design competition for the next upgrade appears to justify the investment.

Table 9.1

Production Savings Needed To Breakeven on Investment in Shadow Competitor

Investment in Shadow Competitor (% of full EMD)	Prime Cost Reduction Needed to Breakeven (Percent)
10	2
20	4

We believe the government would get four benefits from such an annual investment. First, the government would be assured of continued development in technologies and system architectures directly relevant to the JSF. Having such a program in place would provide the institutional structure necessary to support and guide appropriate development work. Second, the government would be able to selectively support a few key firms that might otherwise leave the business of developing fighter aircraft mission equipment, and thus strengthen the industry base for future programs. Third, the shadow competitor would serve as a backup in case the prime developer of mission equipment stumbled in some important way. Finally, the existence of such a program might provide to the prime developer of mission equipment a sense of impending future competition in this important area, thus improving the quality of the main JSF development program.

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[36] Some believe our cost estimates are too low, because of the need to keep 6–10 individual contractors active.

The full implementation of such a strategy has not been fully examined in the present study. We believe this option deserves careful consideration, but its size, scope and structure must depend on more detailed examination.

OPTIONS FOR FUTURE COMPETITION FROM OUTSIDE THE JSF PROGRAM

Numerous near term and longer term options exist for future competition from outside of the JSF program. However, a very quick survey of these options suggests that none of them are particularly attractive for a variety of different reasons.

In the near-term, modifications or upgrades of some existing aircraft could in many areas be viewed as competitive with the CTOL variant of the JSF. Certainly a multi-role air-to-ground variant of the F-22 Raptor, now completing EMD, could equal or surpass the JSF CTOL in most performance areas. A variant of the large, two-engine F-22 however would undoubtedly be considerably more expensive than the JSF CTOL, assuming the JSF program achieves its URF cost goals. An upgraded version of either the F-16D Block 60+ or the F-15C or F-15E, including JSF avionics subsystems, also might equal or exceed the JSF CTOL in many performance areas. Indeed, an advanced F-16 is already being developed for the United Arab Emirates which includes the latest AESA radar technology and other advanced avionics, as well as "fast pack" conformal fuel tanks added to the fuselage for greater range. However, both F-16 and F-15 upgrades would likely fall well short of the JSF CTOL in Low Observability (LO) characteristics, as well as in other areas. Furthermore, an F-15 variant would probably surpass the stringent JSF URF cost goals.

For carrier use, an upgraded version of the F/A-18E/F now going into production is an obvious alternative choice to the JSF CV variant. Indeed, the Navy is already adding an advanced AESA radar and other improved avionics to the existing F/A-18. However, this option suffers from the same problems as the CTOL alternatives: the two-engine F/A-18 variant would likely be more expensive, and lack the LO characteristics of the JSF CV variant.

There is really no plausible near-term alternative to the JSF STOVL variant. The only possibility would be a major developmental program to upgrade the existing subsonic AV-8B Harrier, an aircraft developed in the late 1970s. Such a variant of course would also probably lack the LO characteristics of the JSF STOVL design.

Perhaps most important of all, these options would mean the loss of the substantial learning curve benefits of producing large numbers of variants of the same basic design that is at the heart of the cost savings approach of the JSF program. Instead of all three services procuring

essentially the same basic airframe design and the same mission avionics, three separate modification and upgrade programs of different exiting aircraft would have to be undertaken, each resulting in the procurement of far smaller numbers of unique designs. Thus the economies of scale sought in the JSF program would be lost.

Variants or upgrades of foreign fighters currently under development or in production could also be considered possible alternatives to the JSF, although realistically probably only for foreign customers. Possible alternatives for the JSF CTOL variant include the UK-German-Italian-Spanish Eurofighter, which is now just entering into production; the French Dassault Rafale, also just entering production, and the Swedish Saab Gripen. While high performance modern fighters, the Eurofighter and the Rafale show some of the same disadvantages of the F-15 and the F/A-18: they are both expensive two-engine aircraft with relatively poor LO characteristics compared to the JSF designs. The Rafale was designed from its inception for both land-based and carrier options. The first production Rafale is the Rafale M variant for the French Navy, which could be considered as an alternative for the JSF CV variant. However, the same problems mentioned above apply to the Rafale M. Already in production, the Gripen is a smaller, lighter, less capable F-20 class fighter whose design does not possess the basic performance and LO characteristics of the JSF designs. No STOVL candidates exist in Europe, other than a major upgrade of the existing subsonic Harrier GR.7. Finally, none of these aircraft would provide the benefits of the huge economies of scale sought in the JSF program by using a single basic design to meet all service needs.

In the longer term, more radical modifications of the existing fighters already mentioned above could be considered as alternatives to the JSF. However, the scale of modifications necessary to be truly competitive with the JSF would amount to developing essentially a new aircraft. Thus, no particular advantage would necessarily be gained from taking this route compared to continuing with the existing JSF EMD effort.

In the long-term, radical alternatives such as Unmanned Combat Air Vehicles (UCAVs) might be substituted for some missions envisioned for JSF. Indeed, the US Defense Department recently awarded a contract to Boeing to continue development of its UCAV design. Other radical concepts such as mounting larger numbers of smart stand-off munitions on aerial missile launch platforms such as existing or future bombers, or even modified commercial wide-body airliners, might appear attractive. The type of munitions that could be used might be something like an upgraded Joint Air-to-Surface Stand-Off Missile (JASSM) with an active target recognition sensor for greater accuracy against high value targets even when launched hundreds of miles from the target area. The JASSM is currently in full scale development for the Air Force.

An even more radical concept might be to place weapon launching platforms in space, and launch precision guided munitions from there against land and sea targets. This, as well as many other similar suggestions, are obviously options that might become available only far in the future.

The problem with most of these radical options is that the ultimate effectiveness and capabilities of such future systems are not known at this time. The UCAV and JASSM are being developed, but real capabilities and effectiveness of even the first generation systems that are currently under development are not known. No well developed doctrine or operational concepts exist for the substitution of air breathing or space-based smart munition launch platforms for the traditional combat missions assigned to fighter-attack aircraft such as the JSF. Furthermore, the ultimate cost competitiveness of such systems with the JSF is not calculable at this time.

We conclude, therefore, that if the JSF program achieves its system performance and URF cost goals, that no realistic competitor exists, at least in the short term. Existing stealthy aircraft that might be competitive are too expensive, whereas existing non-stealthy aircraft will lack the operational capabilities of JSF. However, if JSF URF costs begin to escalate, other platforms might become viable alternatives, especially for the CTOL JSF variant. The most obvious would be a down-graded ground-attack version of the F-22, or an upgraded F-16 Block 60+. An enhanced variant of the F/A-18E/F would probably be the most likely candidate for the CV variant of the JSF.

If JSF costs begin to escalate, careful and extensive combat modeling must be conducted to determine the cross-over point between cost and effectiveness, where candidates like an upgraded F-16 or a downgraded F-22 become viable substitutes. At this stage of the JSF program, however, competition from outside the program appears to be limited.

10. CONCLUSIONS AND RECOMMENDATIONS

The JSF's original plan calls for the DoD to select at the beginning of EMD a single winner to develop and produce this next generation fighter aircraft. DoD officials are concerned about the suitability of that plan and asked RAND to examine alternatives.

Our objective in this study was to define a range of opportunities and options open to the DoD to introduce competition into the JSF program, and to assess the balance of advantages and disadvantages offered by each option. The options included near-term actions that might be taken in the 2000–2001 time period, and longer-term actions that might be implemented later in this decade or even beyond, while the JSF is still in production. All aspects of the JSF program were included in the study except the engine, which is currently being competed.

Several criteria are commonly applied to such analysis:

- Reducing production cost
- Reducing operations and support cost
- Reducing cost growth throughout the program
- Encouraging innovation and quality
- Strengthening the industry base

The quantitative analyses we performed were primarily focused on the first two criteria; reducing production cost and O&S cost. The others were considered but at a lesser level of detail.

We examined each competition option, some in more detail and more quantitatively than others, constrained only by the available time (about three months) and the effort level enabled by our client, the Under Secretary of Defense for Acquisition, Technology and Logistics. Throughout the study we obtained critical information from the competing program contractors, and we obtained additional data from the Joint Strike Fighter Program Office. While much of that information was considered competition sensitive by the firms, in this report we present only our own analysis and conclusions, thus permitting unrestricted distribution.

Based on our analyses, we make two recommendations:

- *Stick with the winner-take-all strategy for near-term EMD and production of the JSF.*

Despite the potential advantages that might accrue, we estimate that establishing a competitive production line for part or all of the JSF weapon system would require a front-end investment, together with increases in recurring costs, that probably would not be recovered

through price reductions that may result from competitive forces. Even when considering all possible benefits from such competition, we are unable to make a persuasive case for establishing a competitive production source.

As a corollary, the absence of competitive pressures makes it vital that all government agencies involved in managing the JSF program use every available strategy to control program costs and to ensure high quality standards during production. There is a wide range of contractual and regulatory procedures available to help achieve these goals.

- *Consider establishing a future competitor for the EMD and manufacture of the next major upgrade of mission system equipment.*

The mission system constitutes the eyes, ears and brain of the JSF and provides a powerful contribution to its overall combat effectiveness. Many of the enabling technologies are evolving much more rapidly than are most flight vehicle technologies, and we can expect several major upgrades in mission system during the life of the JSF. It therefore makes sense to begin planning now for the first upgrade.

We suggest investigating the establishment of a "shadow" industry team that would begin developing system architectures and component technologies that would be tailored to the JSF platform but focused on technological advancement, cost reduction, and any new mission requirements that might emerge. The team would be ready to provide competition for EMD on an upgraded mission system at some time in the future. This strategy would ensure that future managers have the option of a competitive second source for designing, and possibly producing, future mission equipment upgrades, an option deemed valuable in the present stage of JSF development but that might not otherwise be available in the future.

Whether it will appear attractive to fund EMD and production by a second source in the future cannot be predicted at this time. There are too many uncertainties regarding the amount of progress made by the "shadow" team, performance of the system prime to that point, general economic conditions, etc. Our rough estimates suggest that such a shadow team could be supported in the near term at 10–20 percent of the annual cost of a full-scale EMD program for the mission system. Such an investment is not trivial but it appears to warrant consideration.

Our charter was to seek ways to inject competition into the JSF program. This appears at the present time to be the most attractive option. Within the scope of our study we were unable to examine the idea in detail; we therefore recommend only that the notion be examined with an appropriate level of care and detail by the JSF management.

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